# Compact Dual-Frequency Dual-Polarization Microstrip Antenna Feed for Future Soil Moisture and Sea Surface Salinity Missions

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June 29, 2006

# Outline

- Introduction
- Technical Development
  - Stacked Patch Design
  - Array Design and Testing
  - MSPA/PALS sky testing
- Conclusions of the Work
- Future Work

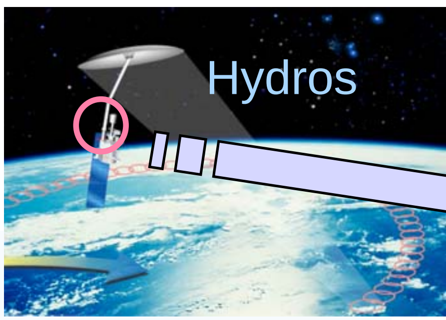
Lightweight Dual-Frequency Microstrip Antenna Feed for Future Soil Moisture and Sea Surface Salinity Missions

- **Objective: Develop a compact dual-frequency antenna feed for future soil moisture and sea surface salinity missions**

Enables: Compact, lightweight antenna feeds for operational soil moisture and ocean salinity radar/radiometer missions

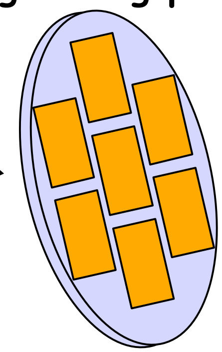
How: Develop a dual-frequency (1.26, 1.29 and 1.413 GHz) microstrip antenna feed

- Reduce the length of feed from 1.2 m to 0.1 m
- Reduce mass from 8kg to 2kg per antenna feed

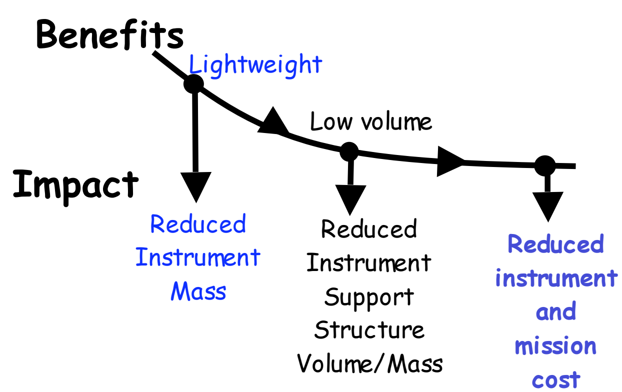




Conical Feedhorn, Orthomode Transducer, and Frequency Diplexer Assembly
- 1 m long
- 5 kg mass



Dual-frequency Microstrip Stacked-Patch Array
- >0.05 m profile
- >2 kg




## Selected NASA ESSP-3 Missions

- **Aquarius proceeding to CDR**
- **Hydros cancelled due to NASA budget constraint**

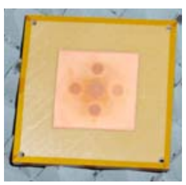
# Key Design Drivers

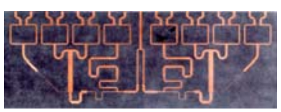
- ✓ Three frequency design to accommodate Hydros requirements (1.26, 1.29 and 1.41 GHz)
  - – Aquarius requires only 1.26 and 1.41 GHz channels
- ✓ Dual-polarization with high polarization isolation (>30 dB)
- ✓ High radiometric calibration stability (Low insertion loss and temperature control requirement)

| | Frequency | Polarization | Polarization Isolation | Radiometer Calibration | Radar Calibration |
|---|---|---|---|---|---|
| Hydros | 1.26, 1.29, and 1.413 GHz | Polarimetric (H and V polarizations for antenna) | >30 dB | 0.7 K | 0.3 dB |
| Aquarius | 1.26 and 1.413 GHz | Polarimetric | >30 dB | 0.1 K | 0.1 dB |

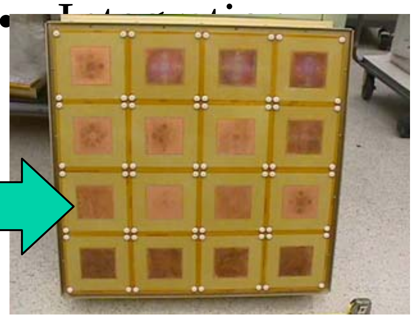
# MSPA Development Activities

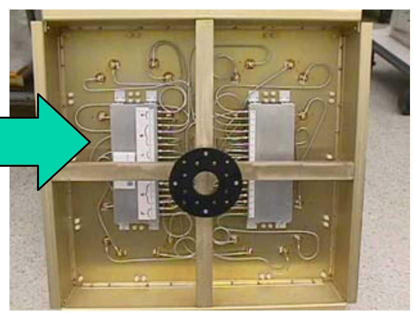
✓ Patch Design
- Array elements
- Power dividers

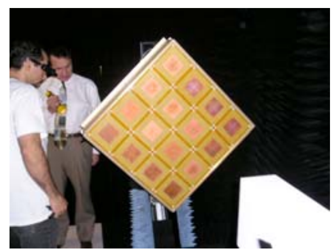




✓ Antenna Design and Assembly
- Frame design and fabrication
- Coaxial cable fabrication







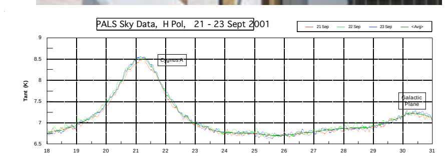
✓ Antenna Range Measurements

✓ Return loss measurements

✓ Radome material testing

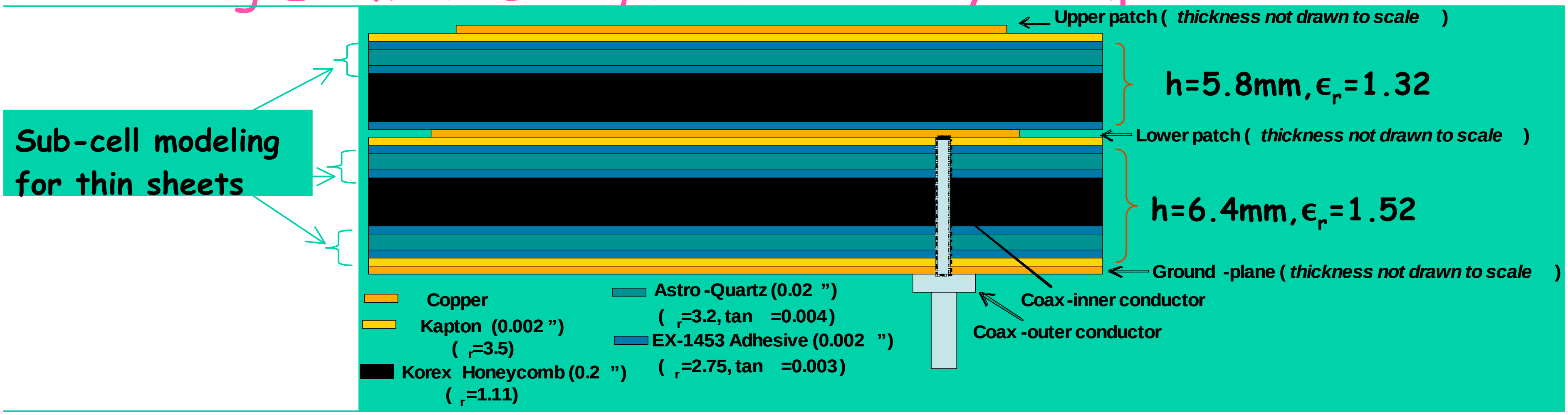
✓ MSPA and PALS Integration

✓ Sky tests

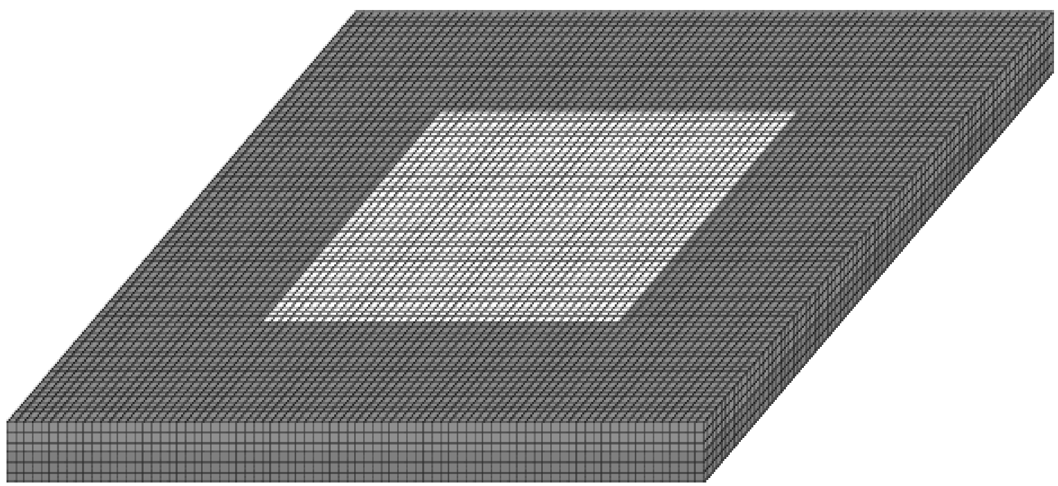


# Stacked Patch Radiating Element Design and Testing

# Radiating Element Design: Parasitically- Coupled Stacked Patch

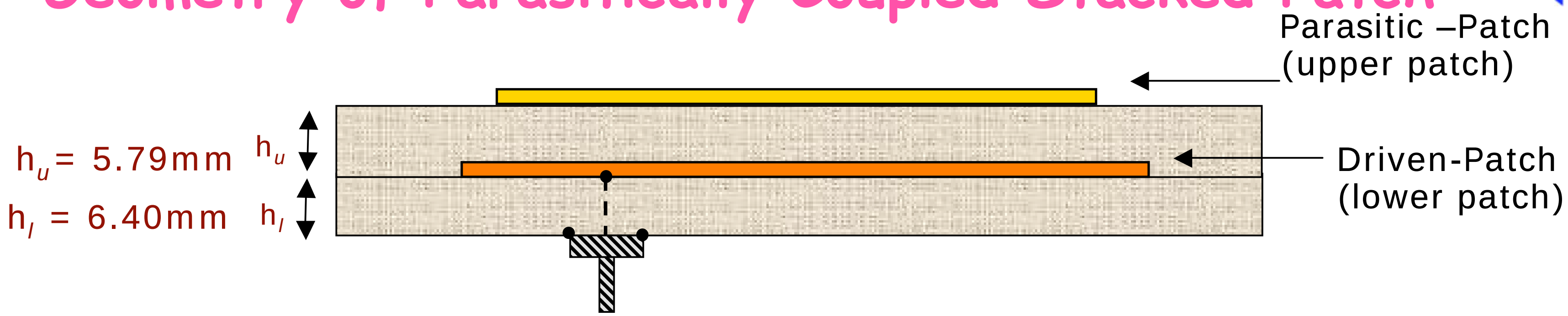


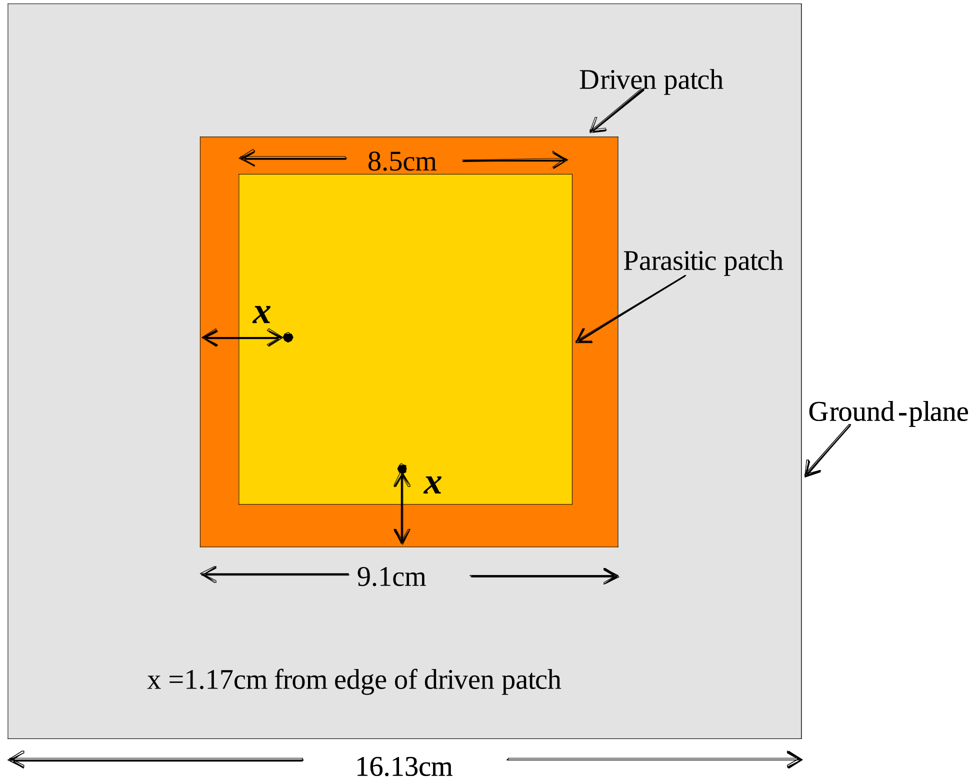

Side-view of a stacked patch element showing the patches and bonding materials



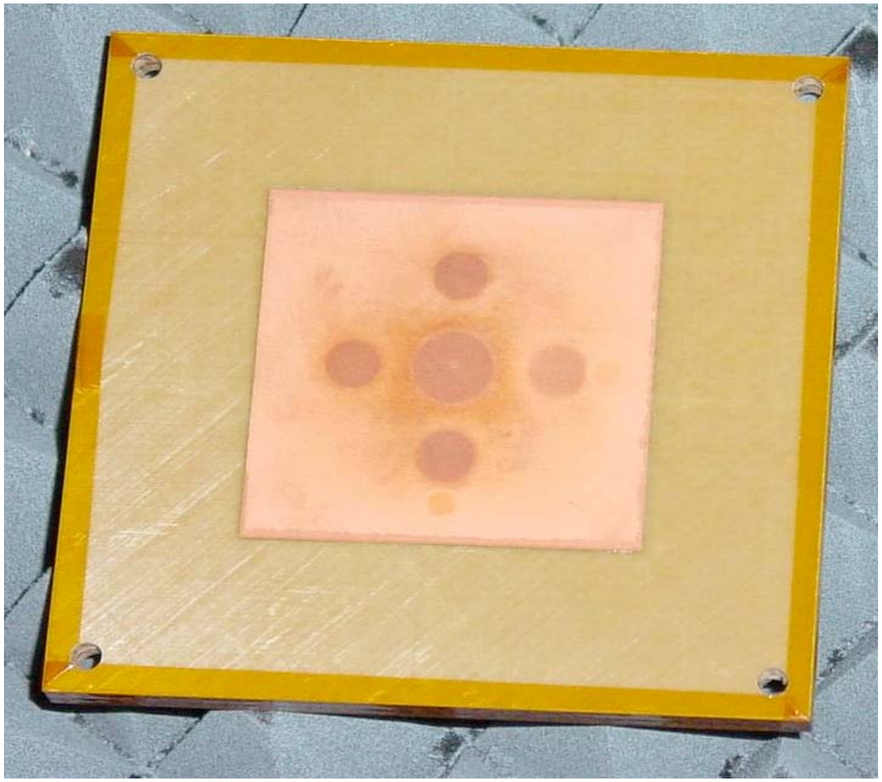
Mesh model used in FDTD for Stacked Patch Element

# Geometry of Parasitically Coupled Stacked Patch



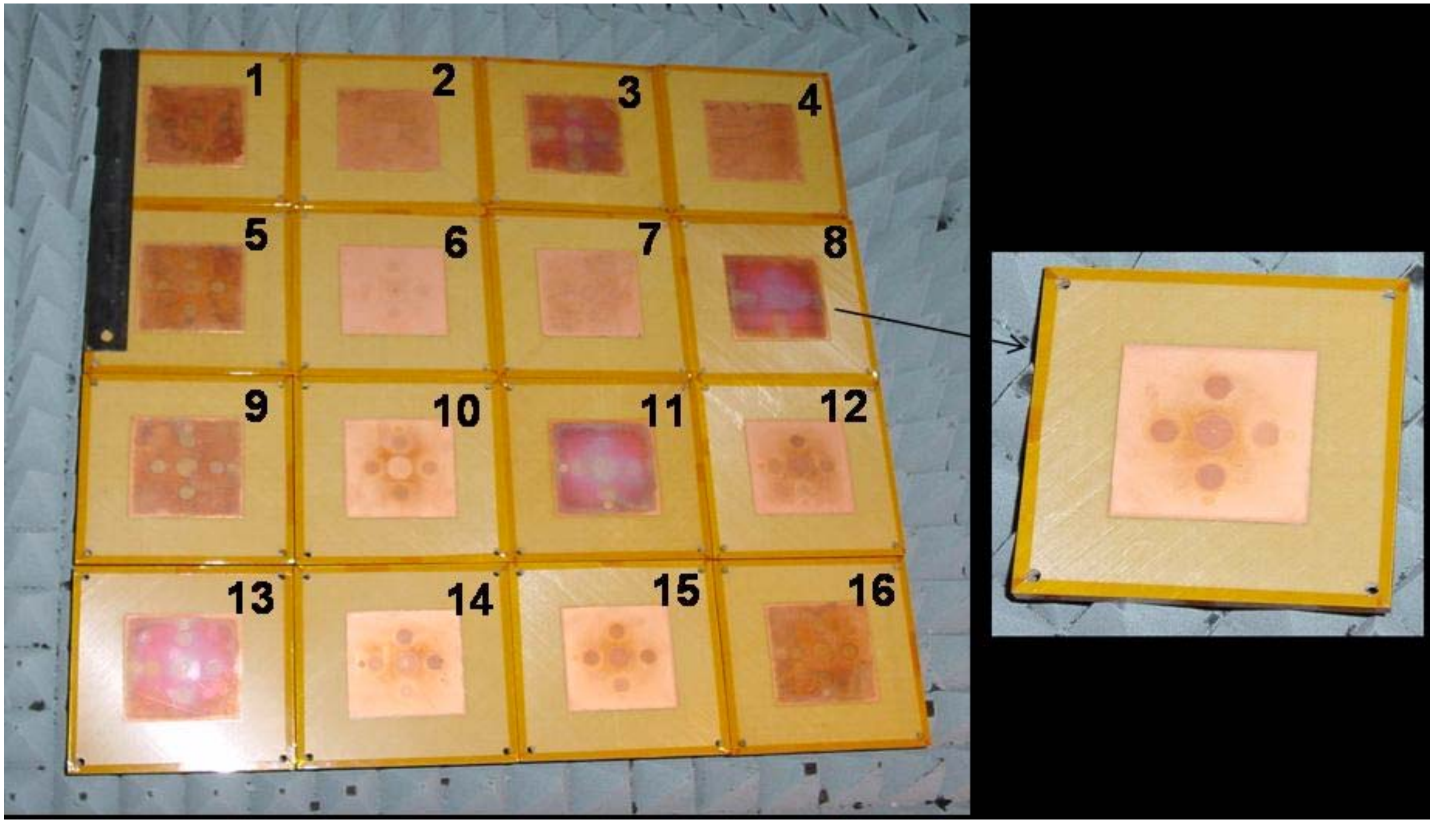




Dimensions of the Stacked Patch Element

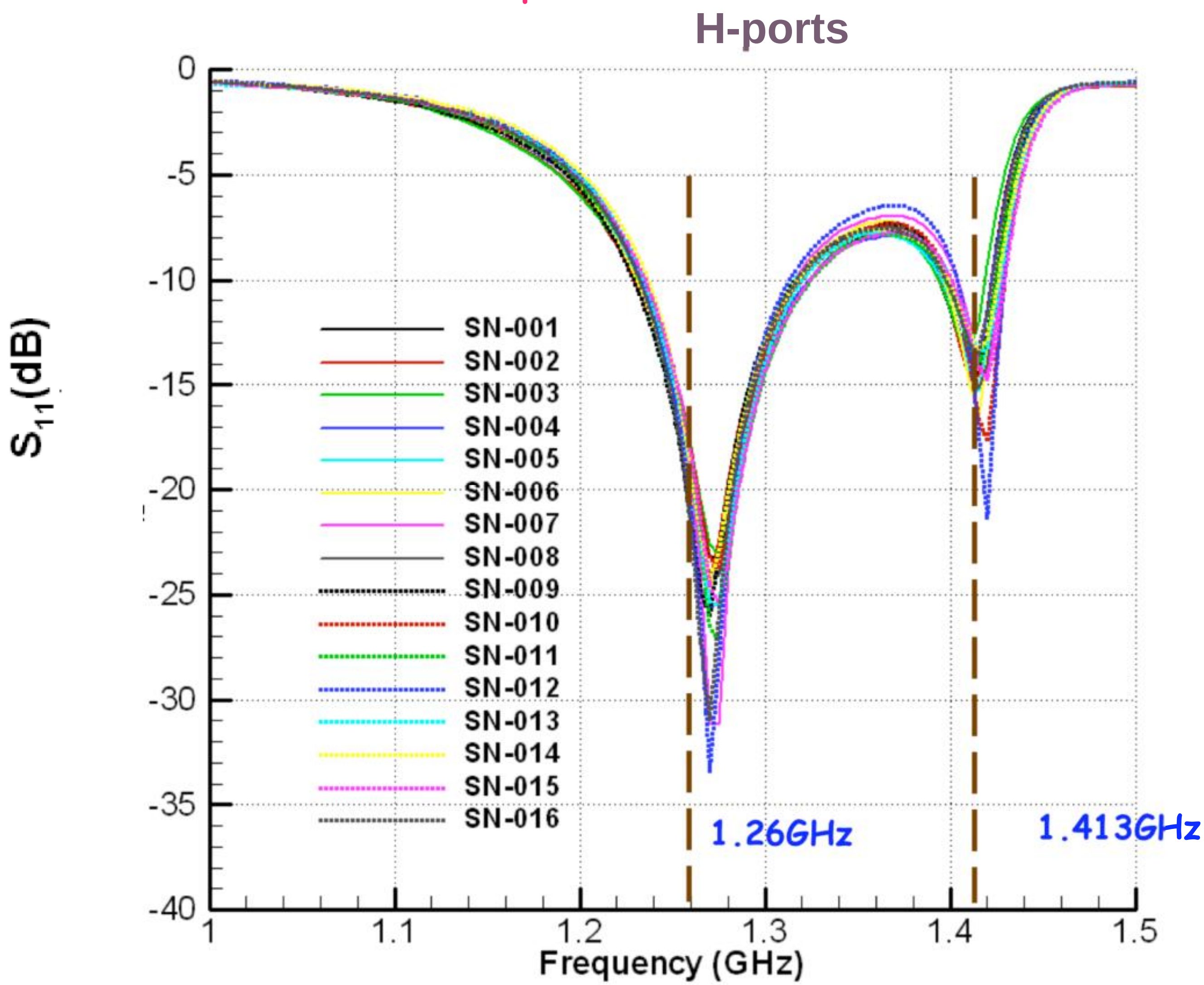


Photograph of the Stacked Patch Element

# Measured Results of Individual 16-elements of the Stacked Patch Array



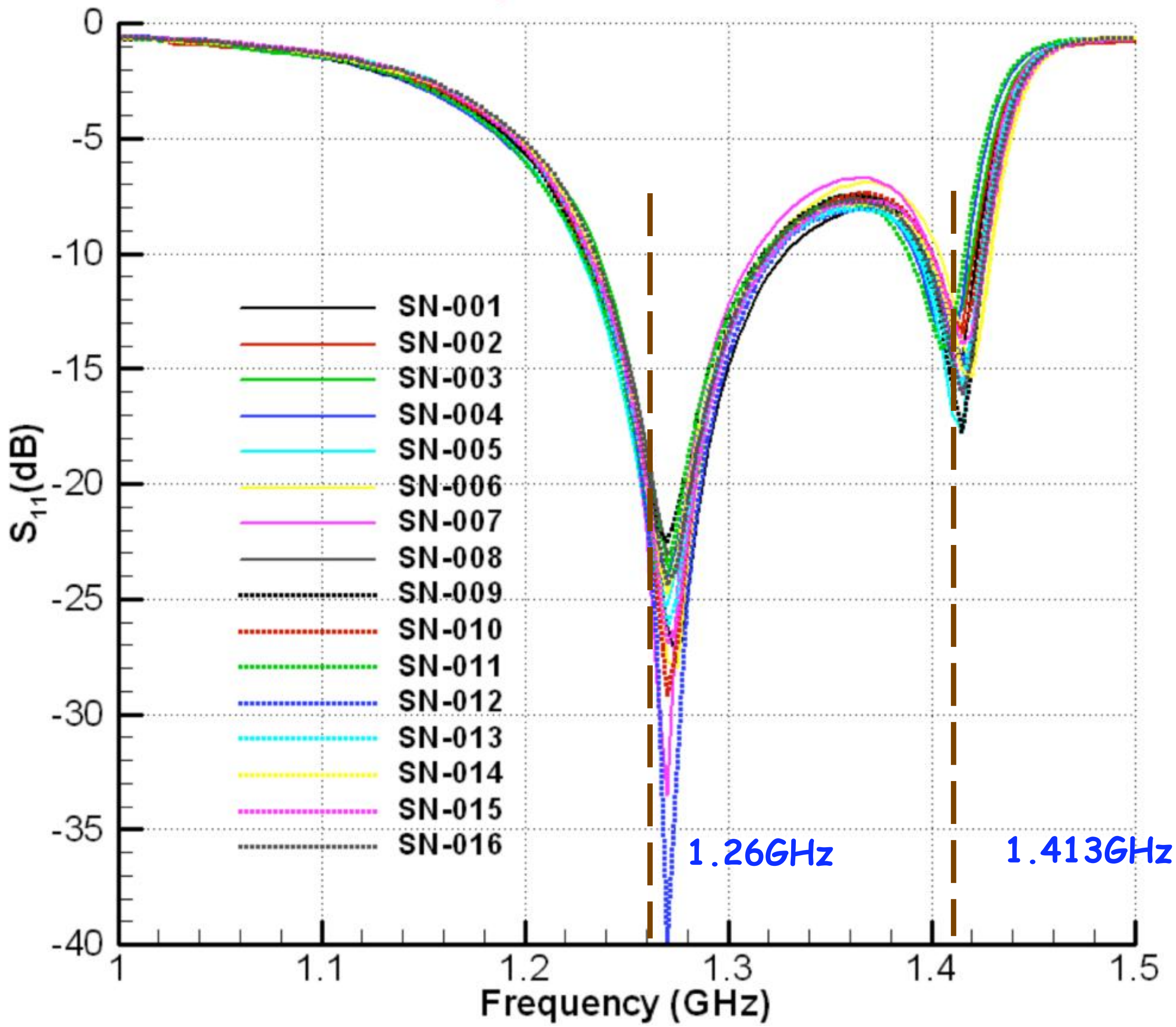
# Measured Return-loss for H-ports of 16-Stacked Patch Array Elements




**The right frequencies of operation with good repeatability and required bandwidth have been achieved for all the H-ports of the 16 array elements**

**Lower patch: 1.26GHz (BW: 90MHz) , Upper Patch: 1.413GHz (BW: 40MHz)**

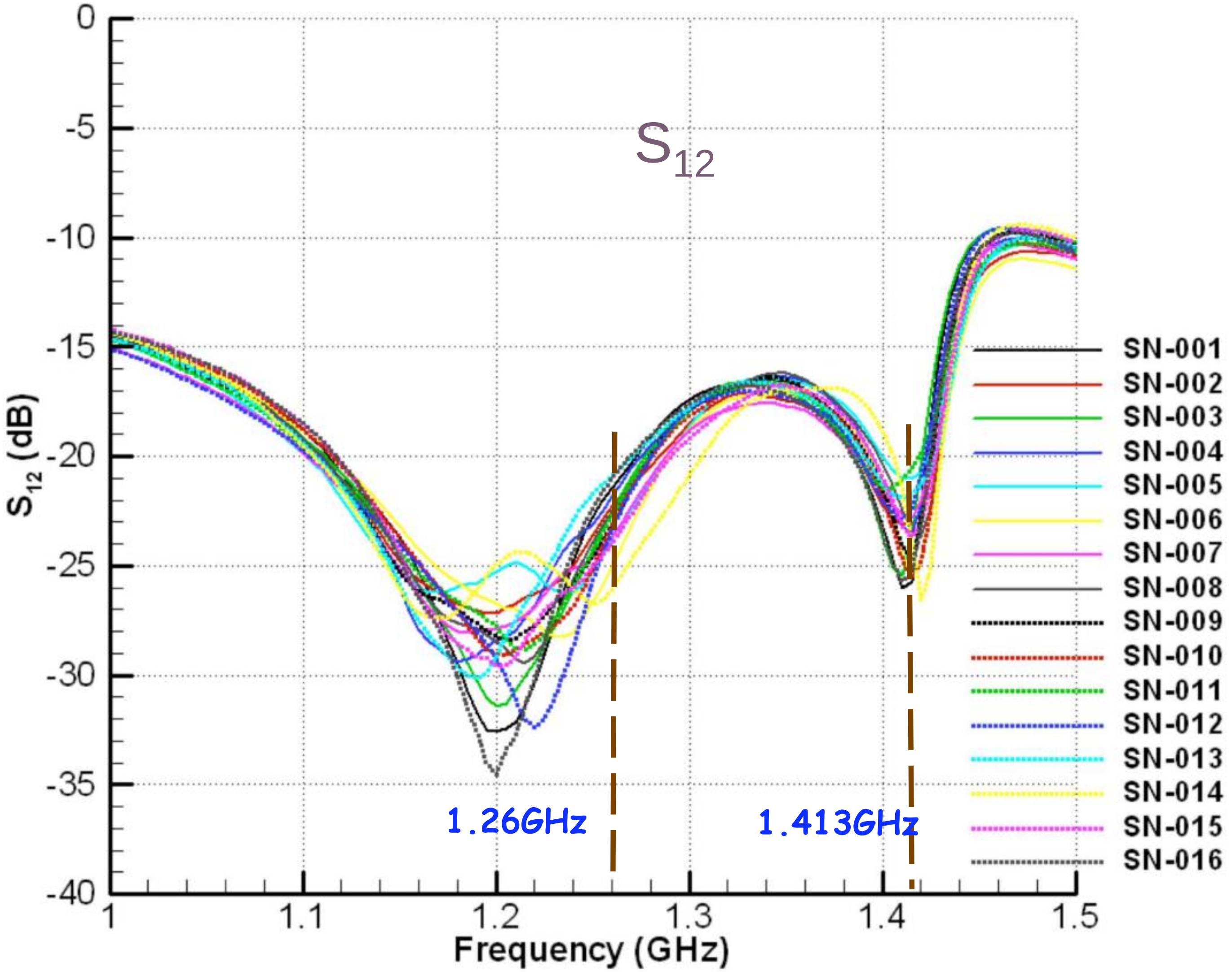
## Measured Return-loss for V-ports of 16-Stacked Patch Array Elements




**The right frequencies of operation with good repeatability and required bandwidth have been achieved for all V-ports of the 16 array elements**

**Lower patch: 1.26GHz (BW: 90MHz) , Upper Patch: 1.413GHz (BW: 40MHz)**

# Measured Isolation between H and V-ports of 16-Stacked Patch Array Elements




**The isolation between H and V-ports at the operating frequencies are below -20dB for all the 16 array elements**

# Array Optimization and Feed Arrangement to Reduce Cross-Polarization

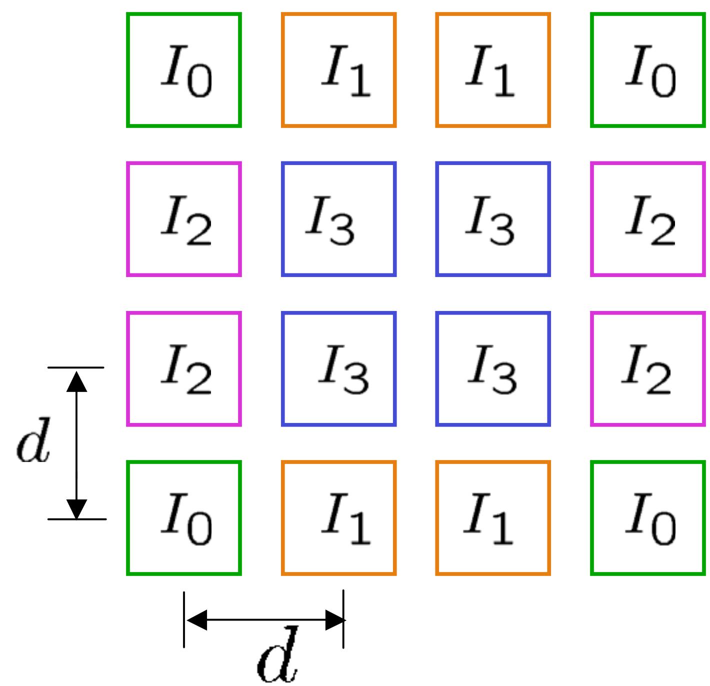
# Array Feed Optimization for Airborne Prototype

- **Optimization parameters:**
  - Element spacing, 0.6 to 1.0 wavelengths
  - Element excitation, 0 to 1.0 amps.
- **Fi**

$$F = \left(100 - 100\frac{P_{beam}}{P_{total}}\right)^2$$

B... 1.413GHz

$$\vec{x} = \{d, I_0, I_1, I_2, I_3\}$$



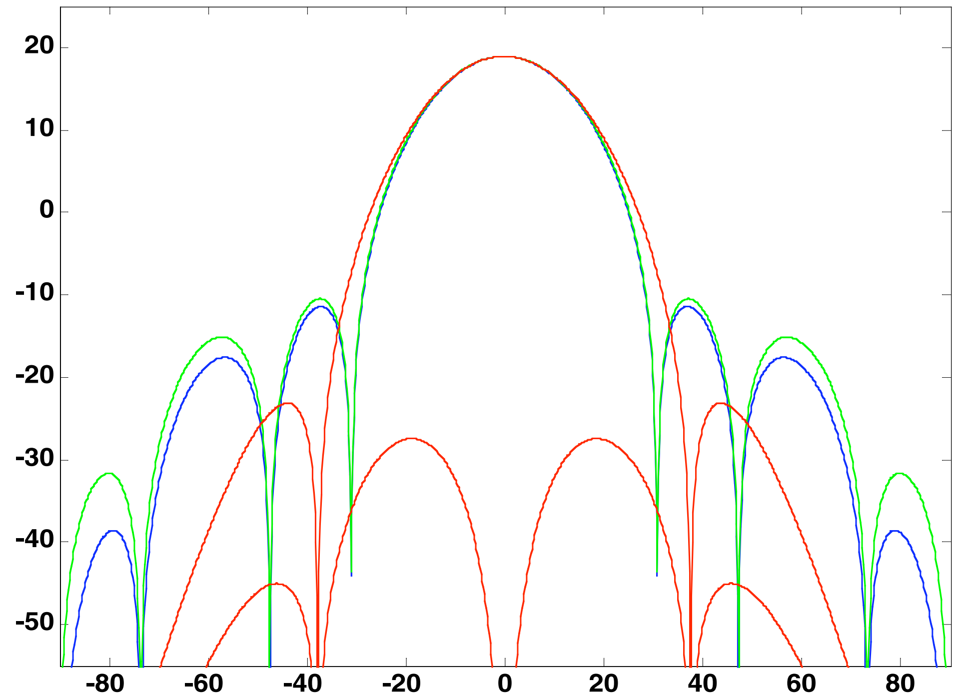
# Optimized Array (1.26 GHz)

Numbers are dB down
from center elements.

| | | | |
|---|---|---|---|
| -13.87 | -6.36 | -6.36 | -13.87 |
| -6.36 | 0.00 | 0.00 | -6.36 |
| -6.36 | 0.00 | 0.00 | -6.36 |
| -13.87 | -6.36 | -6.36 | -13.87 |

$$d = 0.76\lambda_{1.41GHz}$$

**Same feed network as for 1.41 GHz.**




**Optimized Pattern:**

Freq. = 1.26 GHz
Directivity = 18.83 dB
HPBW = 22.4 degrees

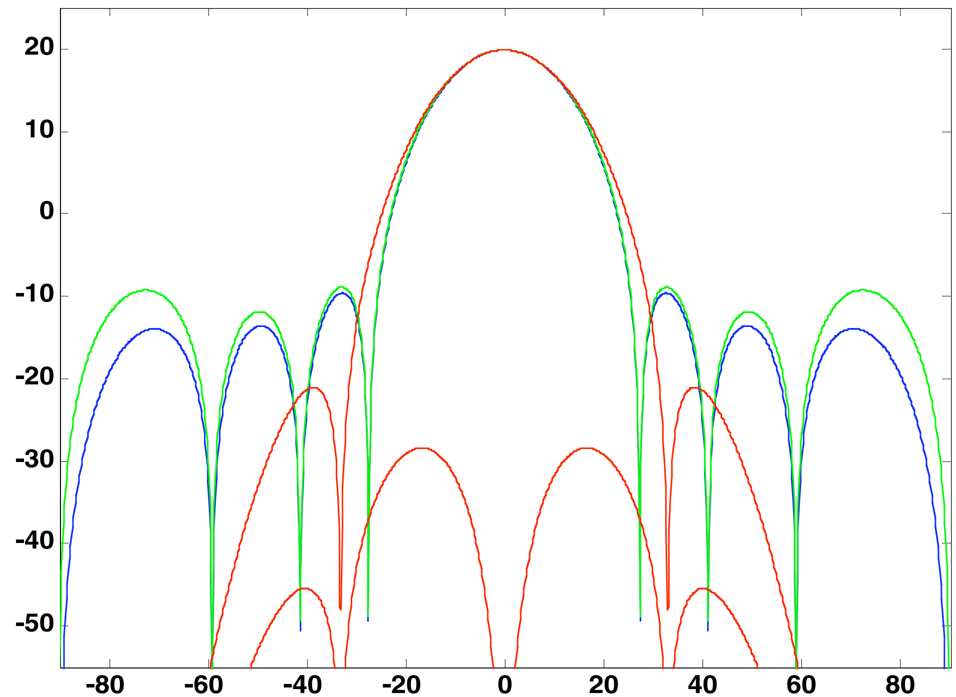
No effect of back-radiation has been incorporated in calculations

# Optimized Array (1.413GHz)

Numbers are dB down
from center elements.

| | | | |
|---|---|---|---|
| -13.87 | -6.36 | -6.36 | -13.87 |
| -6.36 | 0.00 | 0.00 | -6.36 |
| -6.36 | 0.00 | 0.00 | -6.36 |
| -13.87 | -6.36 | -6.36 | -13.87 |

$$d = 0.76\lambda_{1.41GHz}$$

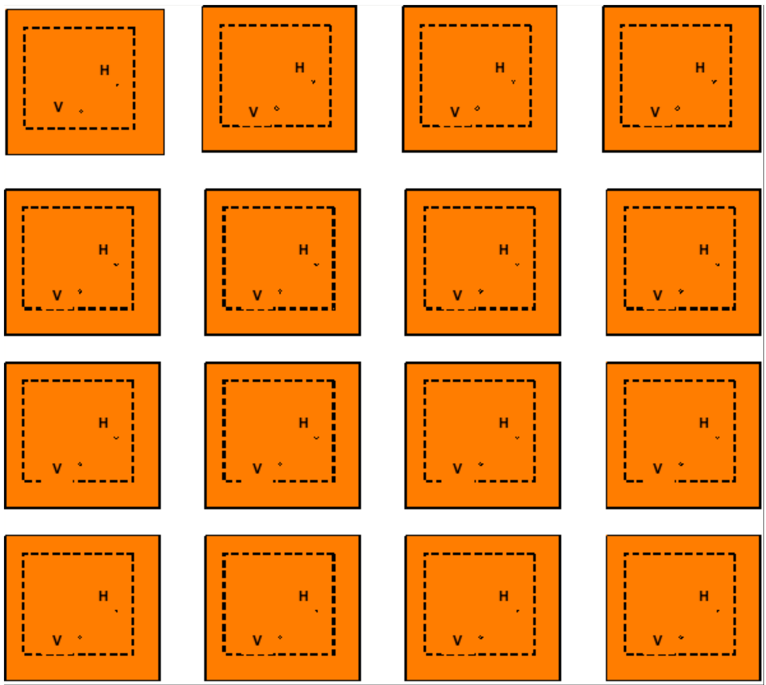



**Optimized Pattern:**

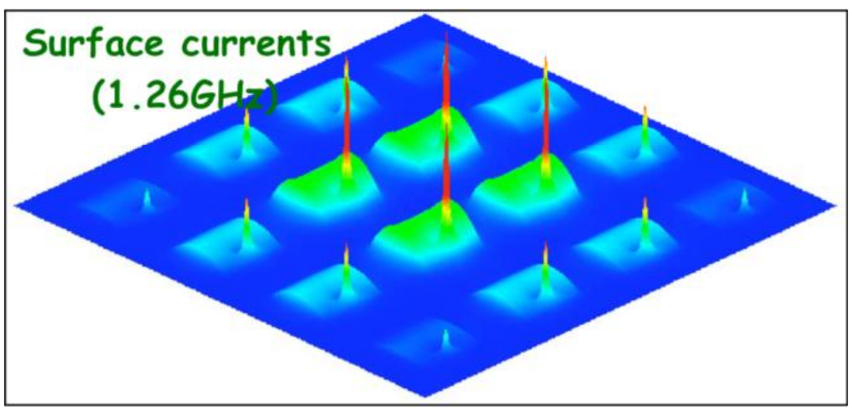
Freq. = 1.41 GHz
Directivity = 19.98 dB
Beam efficiency = 99.2%
HPBW Eplane = 19.8 deg.
HPBW Hplane = 20.2 deg

No effect of back-radiation has been incorporated in calculations

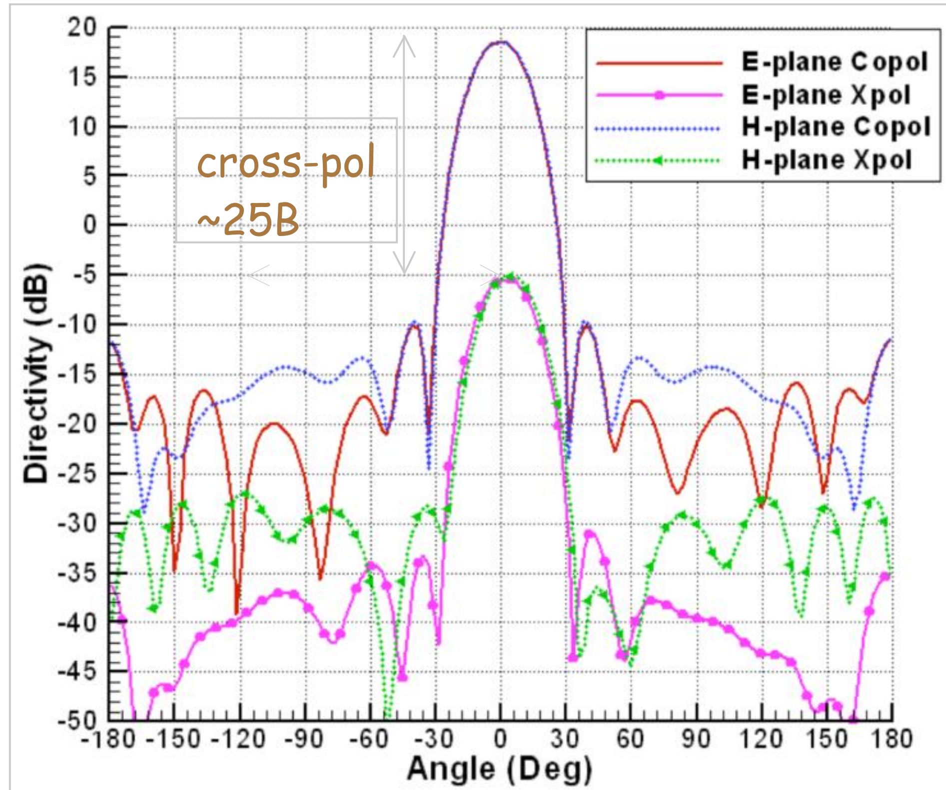
# Feed arrangement to reduce cross-polarization and improve isolation




Baseline configuration

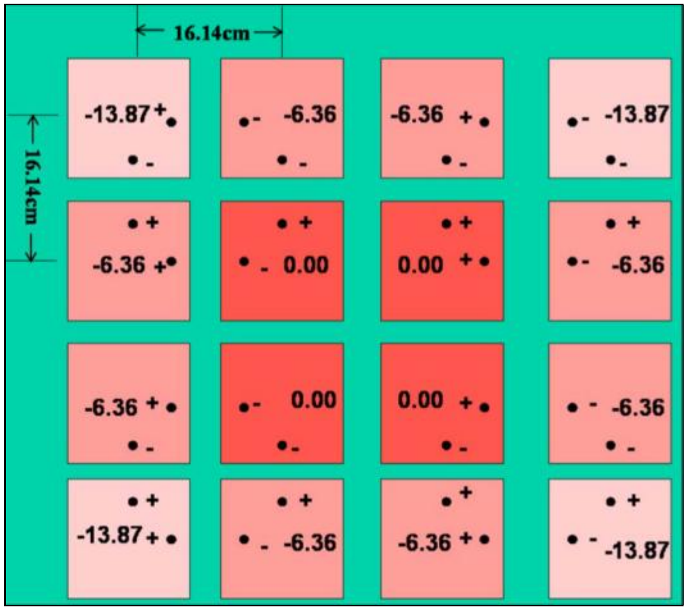


Surface currents (1.26GHz)

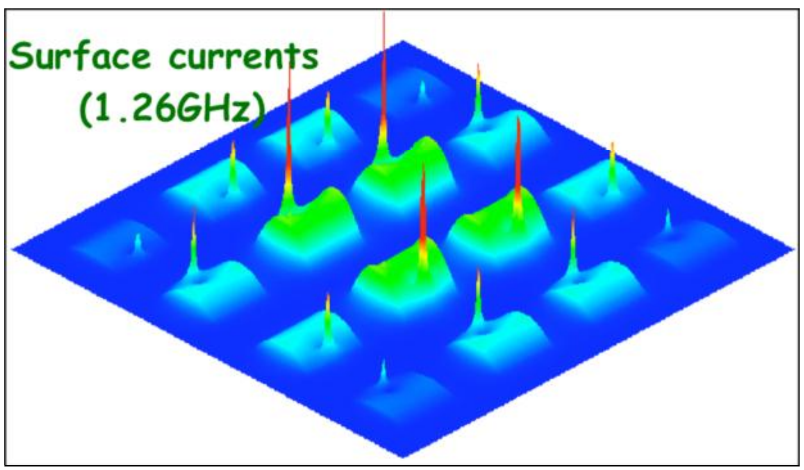


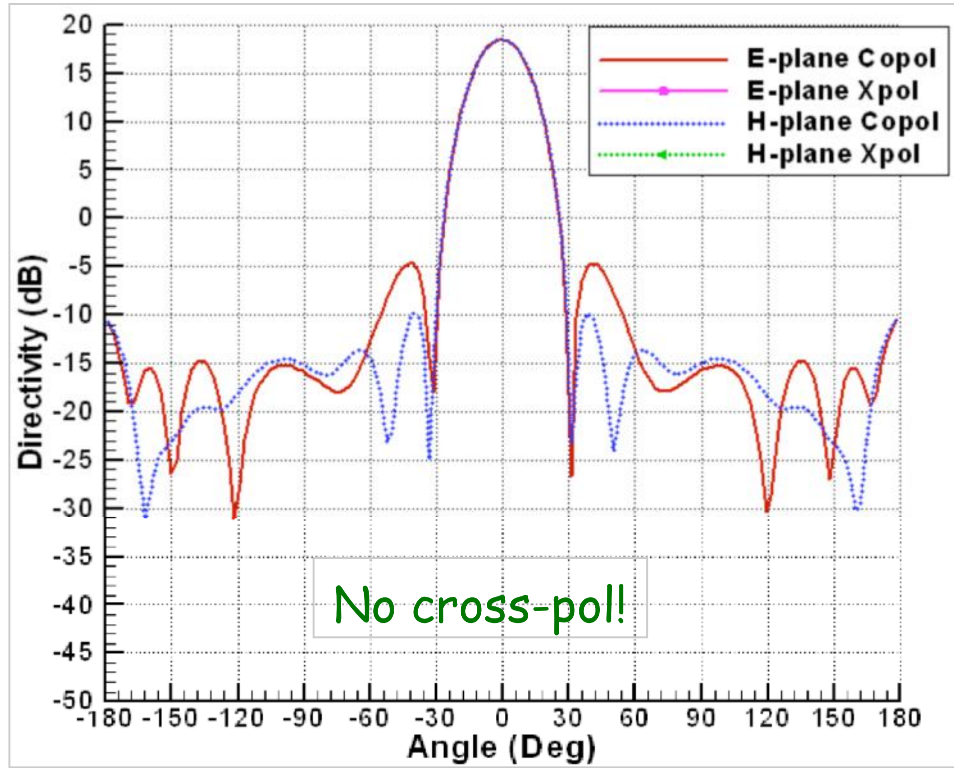

Far-field patterns

# Feed arrangement to reduce cross-polarization and improve isolation




Mirrored symmetry: vertical and horizontal planes

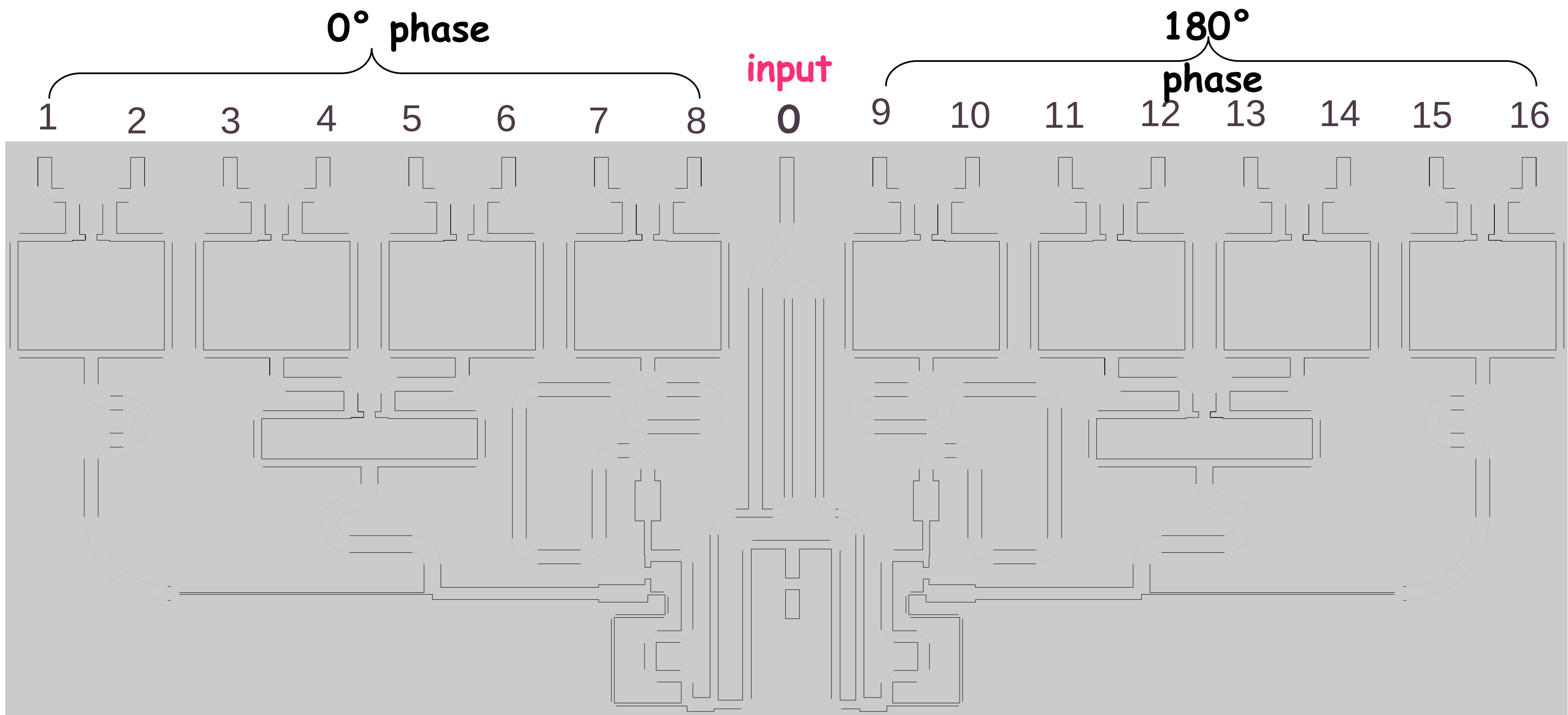



Far-field patterns

# Feed Network Design and Prototype

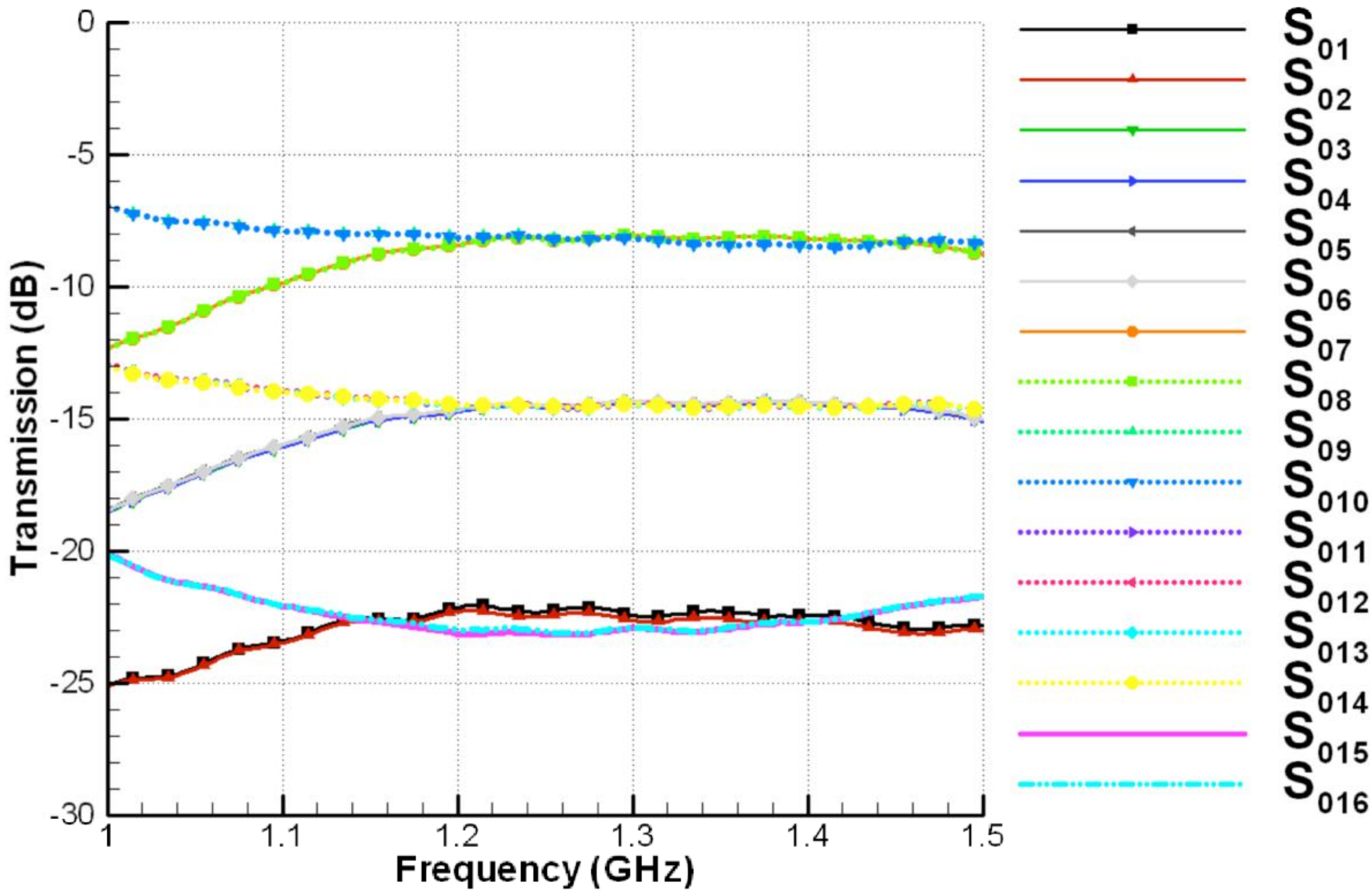
## Design of 1:16 Power Splitter




Remarks:

- All the output ports are matched to 50Ω.
- Considers the required phase for mirrored arrangement of antenna elements
- The overall insertion loss with eight repeated measurements was -0.289±0.05dB at 1.26GHz and -0.251dB±0.05dB at 1.413GHz

# Measured Transmission of 1:16 Power Splitter

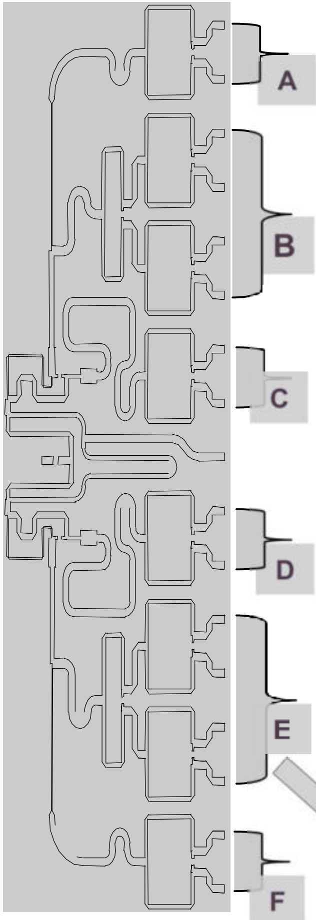



Transmission parameters between the input port and the sixteen output ports

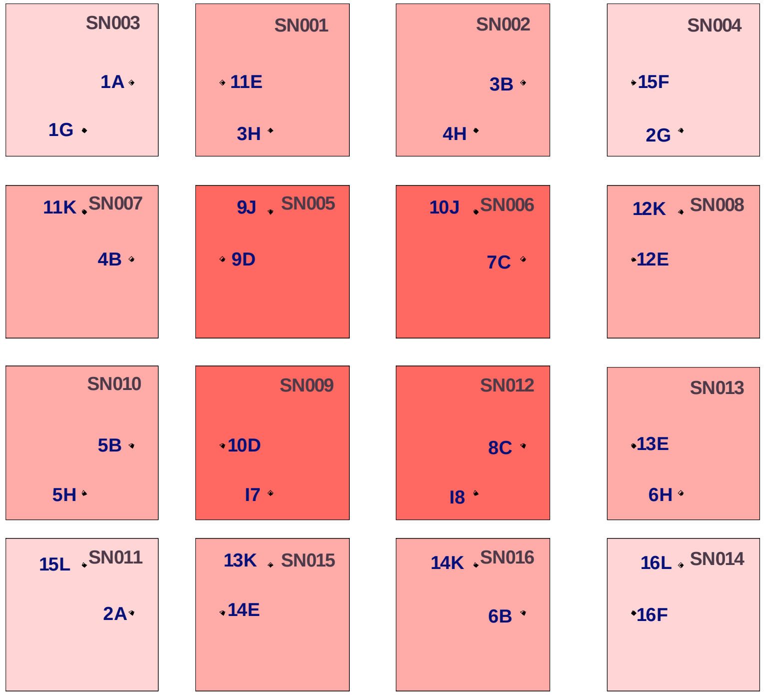
Ports 4, 5, 6, 11, 12, 13 and 14 are -6.36dB below ports 7, 8, 9 and 10 (feed center-elements of array) and ports 1, 2, 15, 16 (feed for edge elements) have -13.87dB taper with respect to ports 7, 8, 9 and 10.

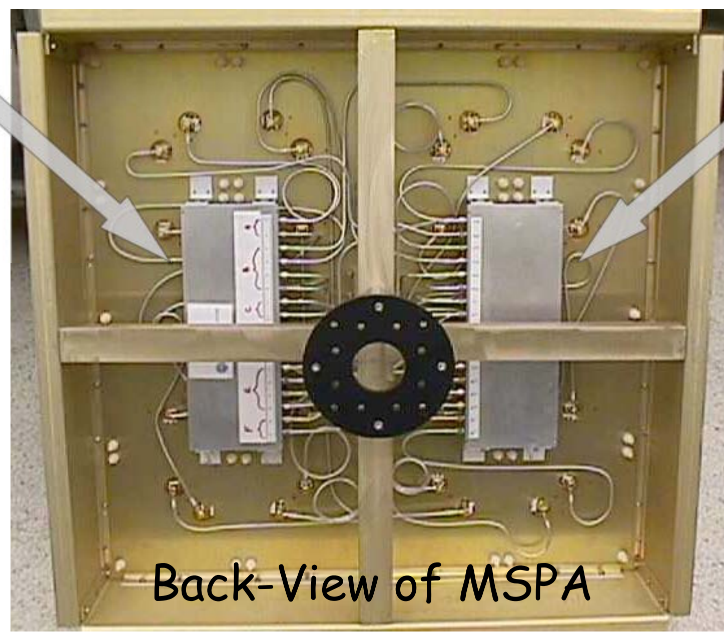
# Measured Results of Sixteen Element Stacked Patch Array

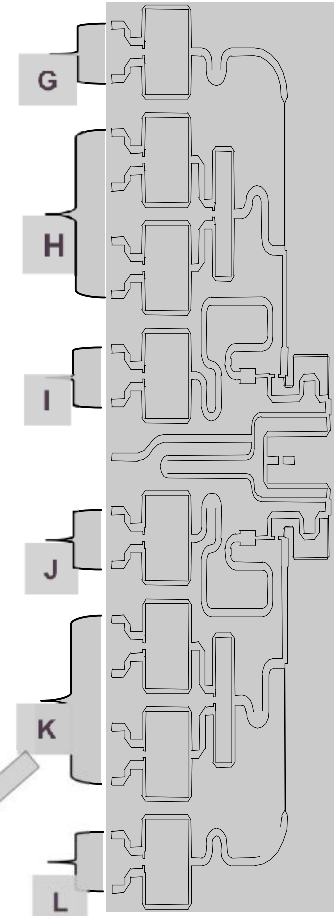
# Port Connections for the Power-dividers and Back-View of stacked Patch Array




Power-divider
(H-ports)




Power-divider
(V-ports)

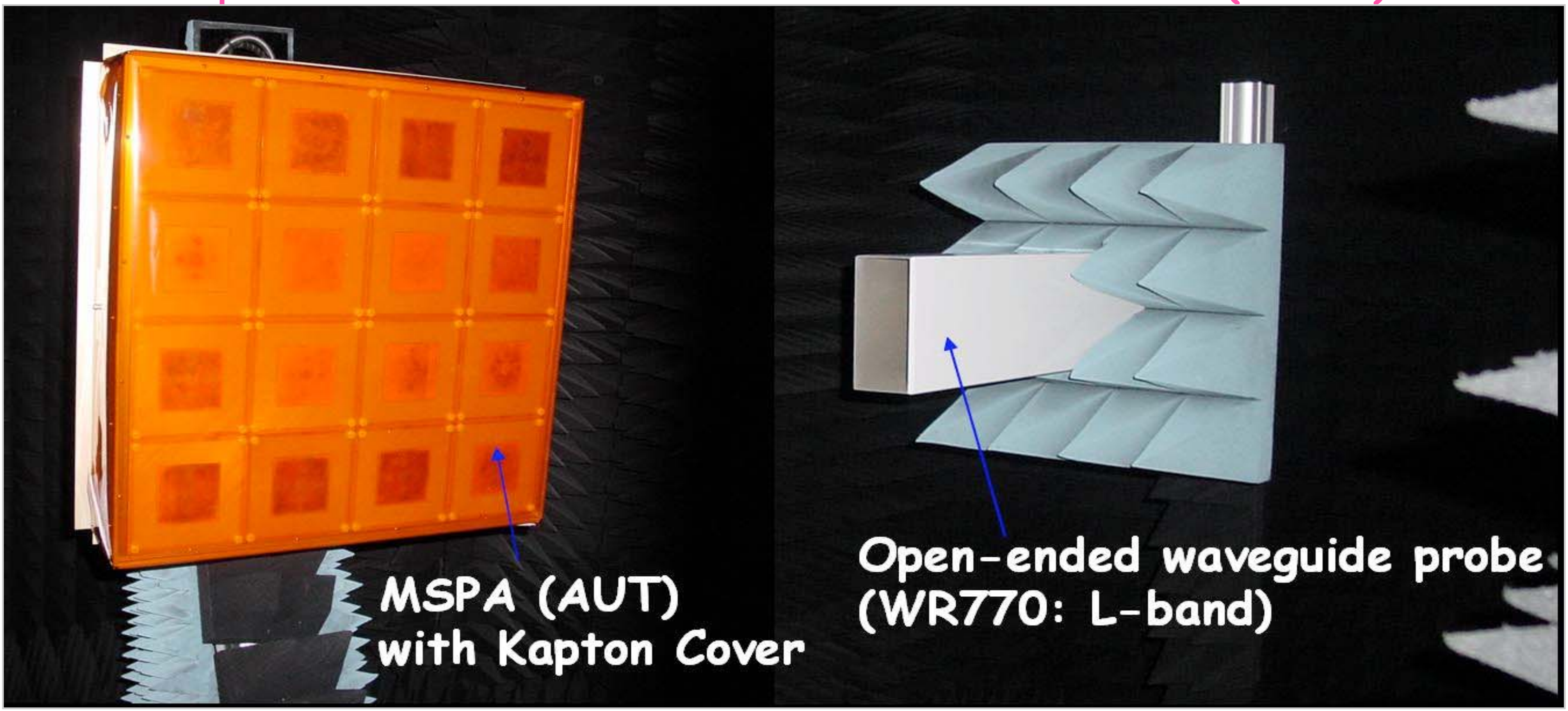
Overall insertion loss for 8 repeated measurements

1.26GHz:-0.289 ± 0.05dB

1.413GHz:-0.251 ± 0.05dB

# Radiation Pattern Measurement Set-up

## Spherical Near-Field Measurement Chamber (UCLA)




Front-view of the Sixteen Element Square Microstrip Stacked Patch Array (MSPA) mounted in Spherical Near-field Test Facility at UCLA

**Measurement Procedure:**

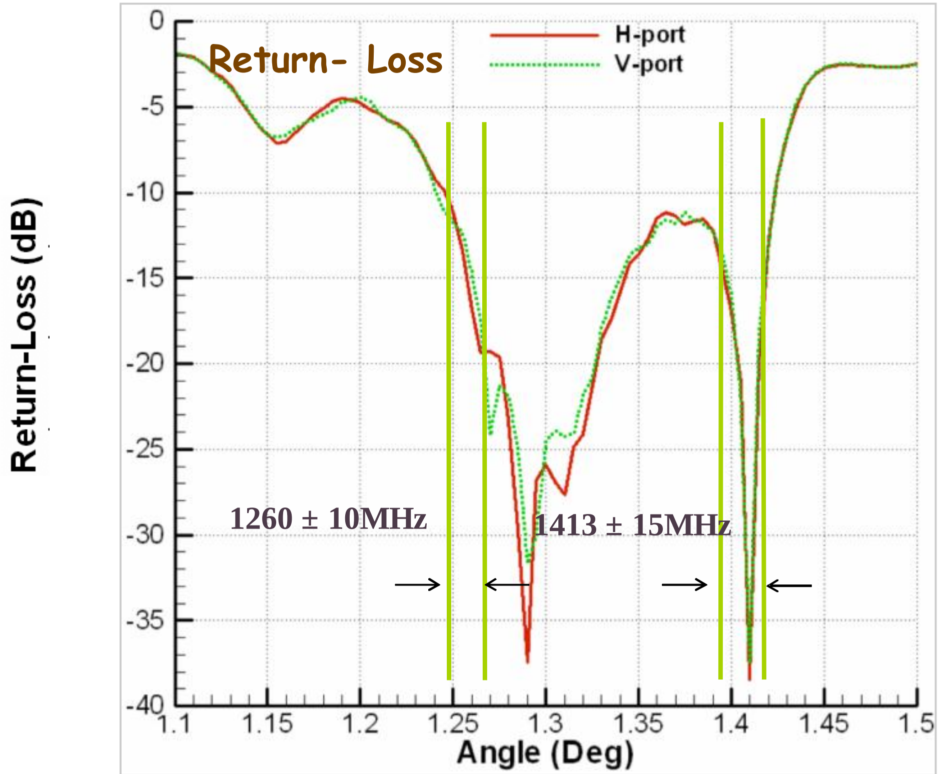
In the spherical near-field test set-up, the amplitude and phase of the fields are measured over a spherical scanning surface surrounding the Antenna Under Test (AUT: MSPA).

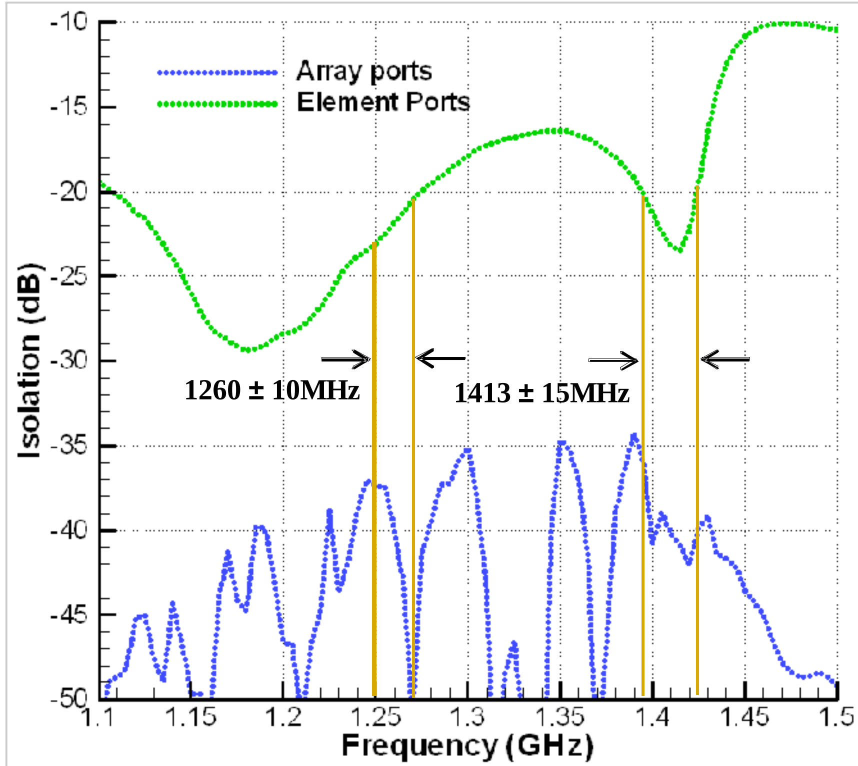
The field probing antenna, an Open Ended Waveguide (OEWG) –WR770 (0.95-1.45GHz) is placed in the radiative near-field of the AUT (3λ).

The far-field is computed from the NSI Inc., software that uses spherical mode expansions of near-fields.

JPL

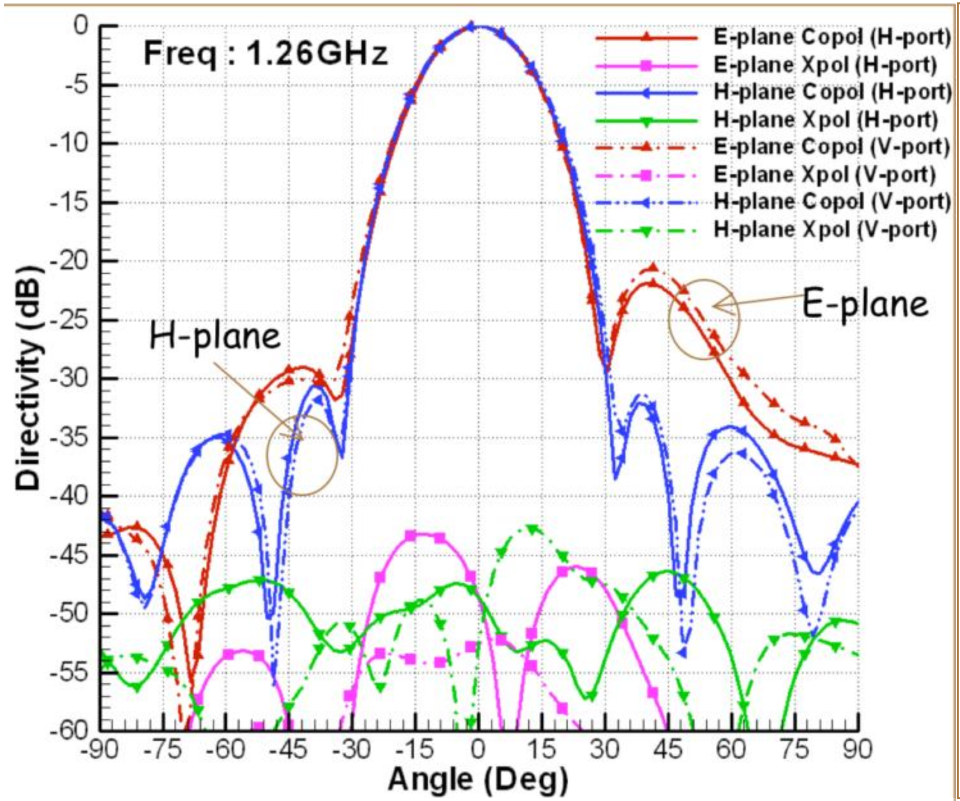
# Measurement Results for 16-Element Stacked Patch Array

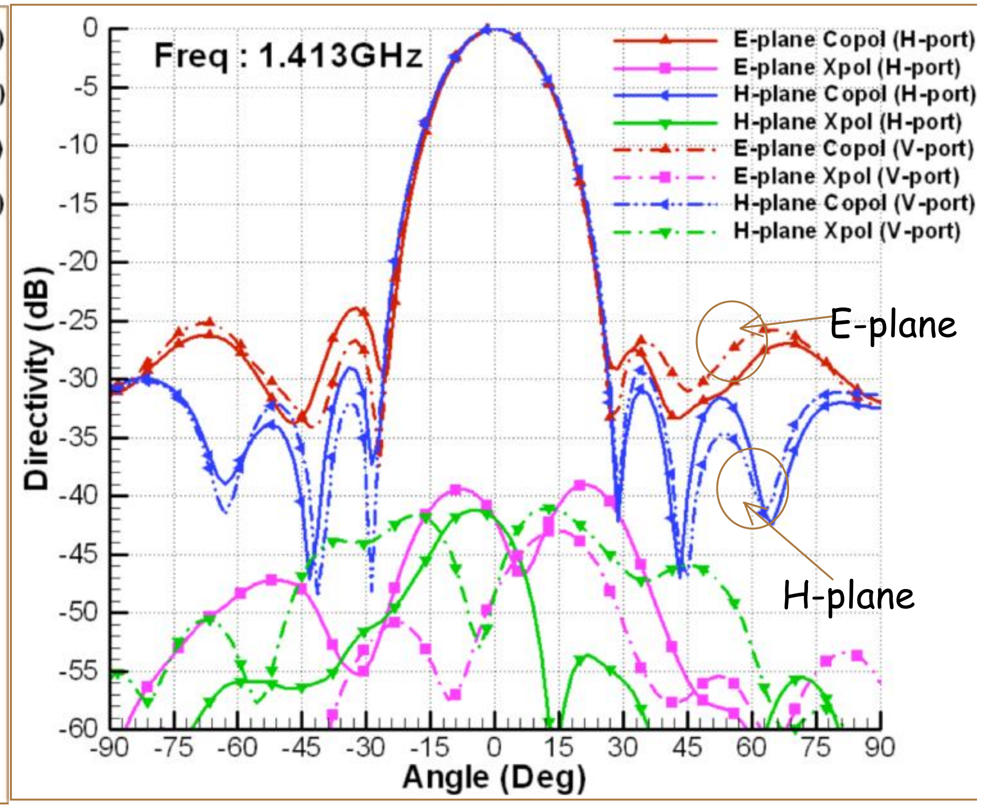



Significant improvement in isolation ($S_{12}$) between ports is observed for array compared to individual radiating element

# Radiation Pattern Measurement Results for Array

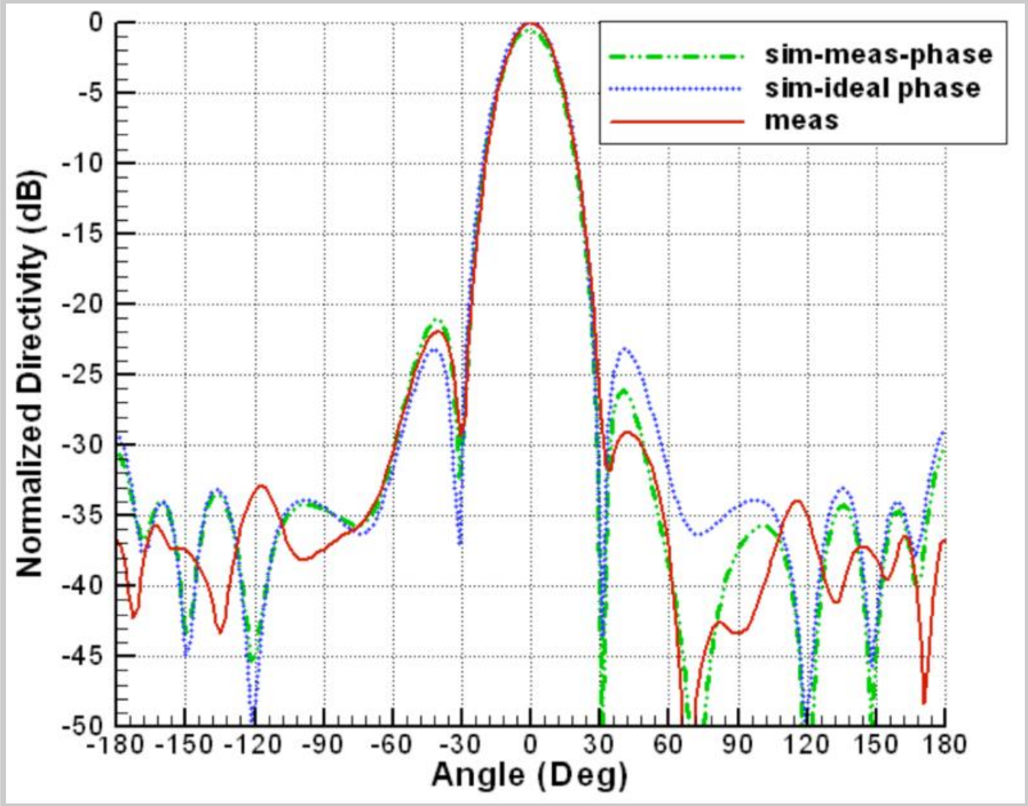



- Symmetric pattern in the main beam region for H and V-polarizations with identical beamwidths

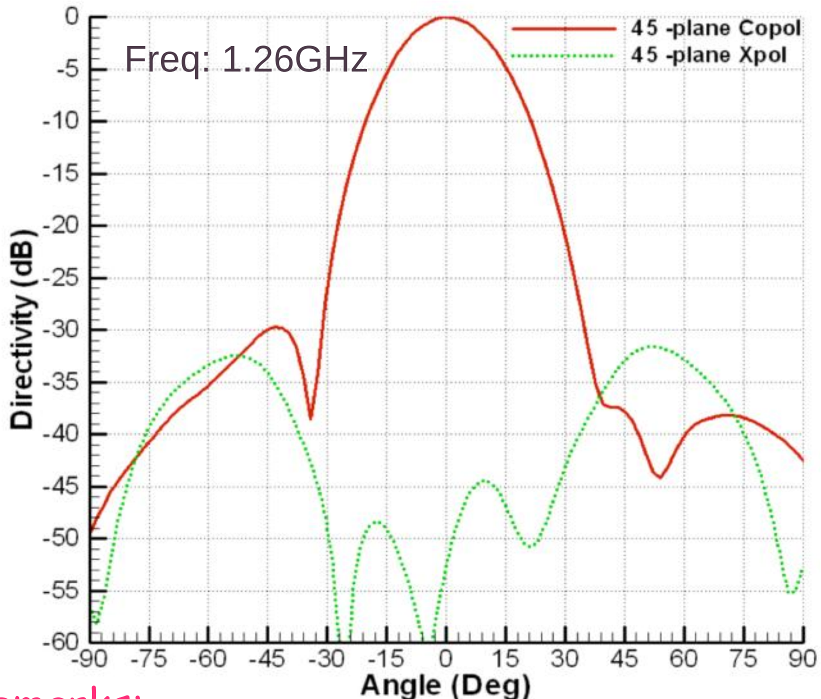
- The cross-polarization is <-40dB in the main-beam region of the array.

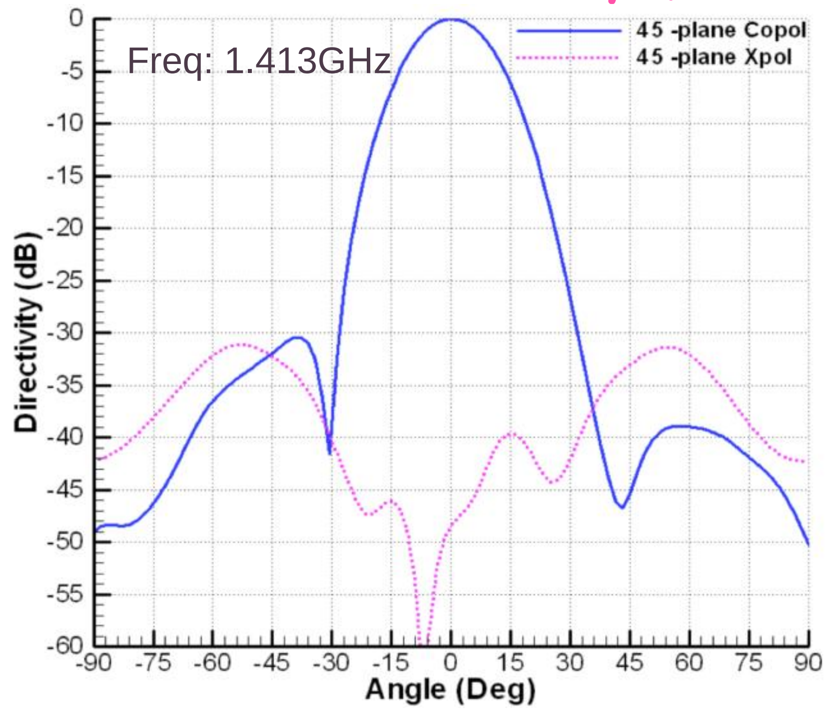
# Comparison of Measurement and Simulation Results




| Ideal amplitude | Actual measured amplitude |
|---|---|
| (0.160, 0.380, 0.380, 0.160) | (0.154, 0.374, 0.374, 0.153) |
| (0.380, 0.790, 0.790, 0.380) | (0.374, 0.772, 0.771, 0.374) |
| (0.380, 0.790, 0.790, 0.380) | (0.380, 0.790, 0.790, 0.380) |
| (0.160, 0.38 0, 0.380, 0.160) | (0.150, 0.380, 0.380, 0.154) |

# Measured Pattern for 16-Element Stacked Patch Array (45-Plane)




Remarks:

- The side-lobe levels are low but the cross-polarization levels are higher (-30 dB) outside of the main-beam region compared to the principal planes.
- The main source of cross-polarization is the fringing fields that are oriented 90° with respect to the field in the main polarization. Their contribution to the E and H planes can be minimized however they are maximum in the inter-cardinal (45-plane) planes.
- This is a well established phenomenon in the far-field pattern of arrays where the cross-polarization field levels in the 45-plane is higher than the cross-polarization levels in the

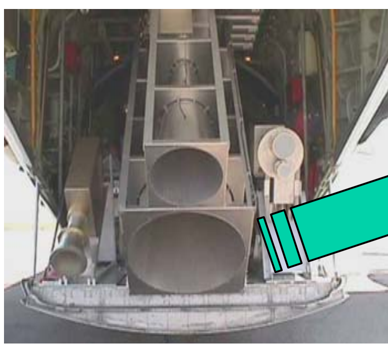
# Cold Sky Test for Insertion Loss And Integration with PALS

# MSPA/PALS-II Plan and Status

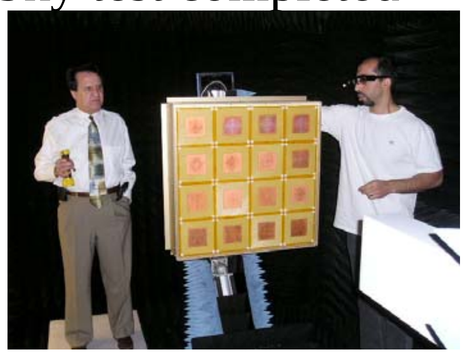
By July 2006 | Summer 2007

NCAR C-130 aircraft used for PALS Mission

Passive Active L/S-band (PALS) Instrument on the C-130 aircraft



- Full array completed and tested in Jan 2005
- Greater than 35 dB polarization isolation
- Sky test completed



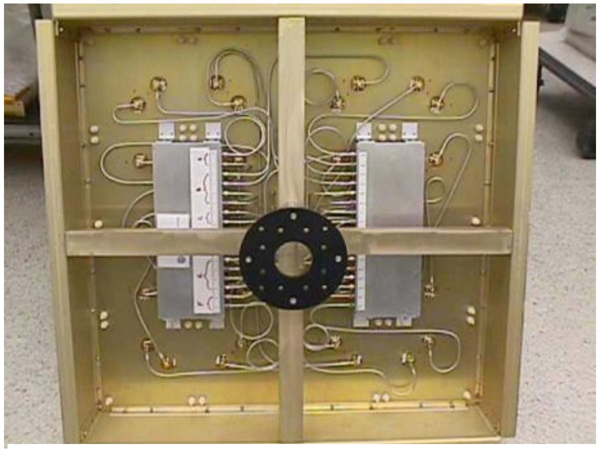
- Polarimetric upgrade completion in 2005

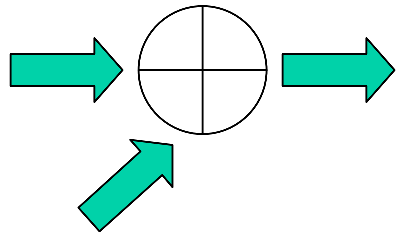
- Science field experiments on Twin-Otter

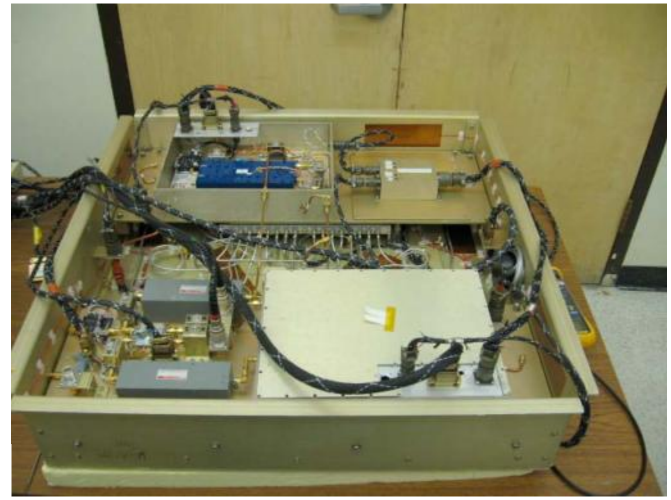
Twin Otter

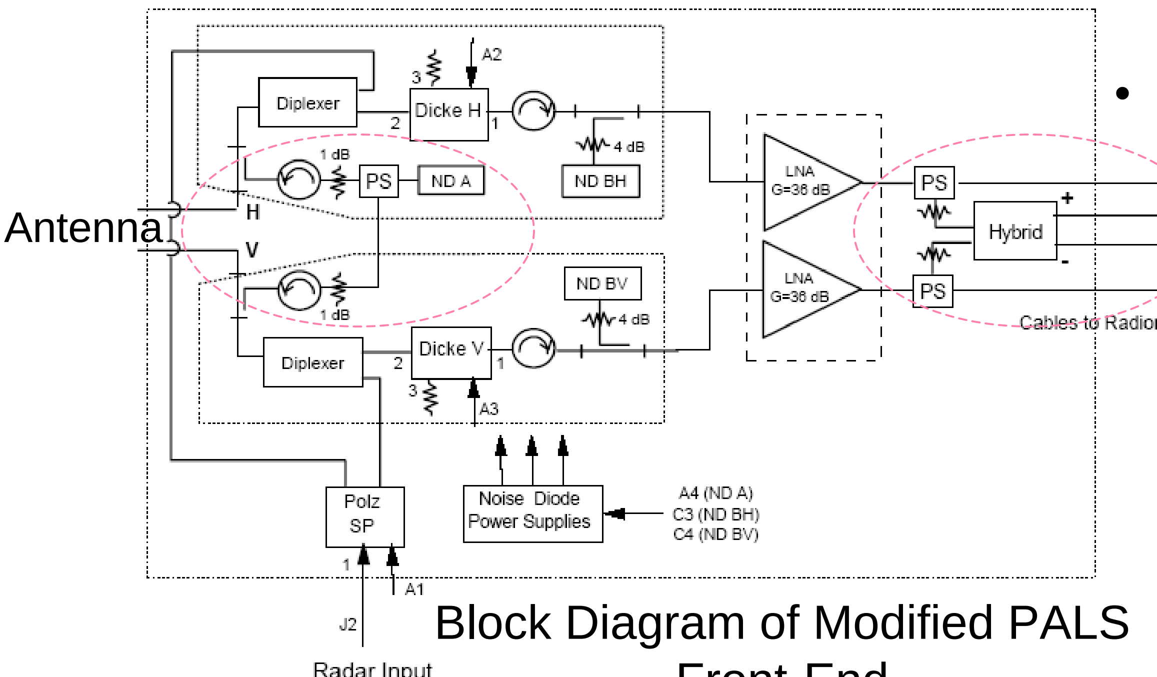
- **PALS-II on Twin Otter proposal selected for funding from Hydrology program for field experiments**

# PALS Front-End Modification and Integration with MSPA










Block Diagram of Modified PALS Front-End

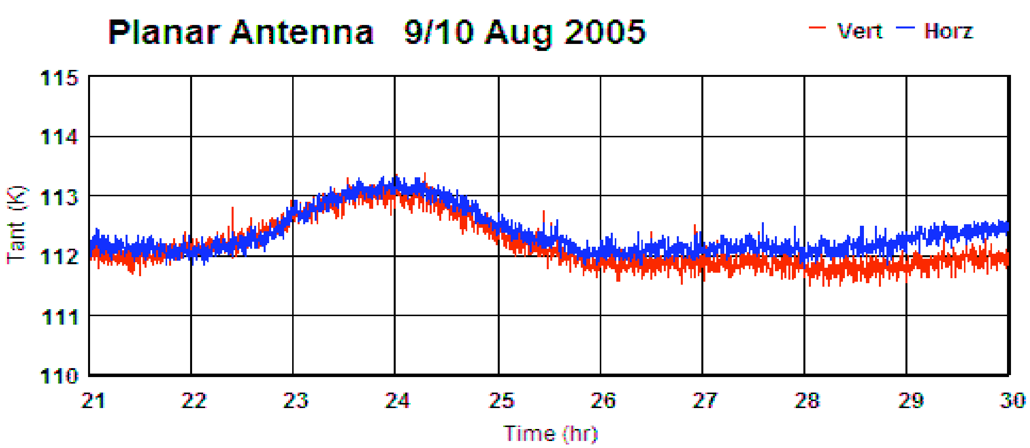
- PALS Front-End modified to mimic the Aquarius design
  - Correlated noise injection into the frequency diplexers
  - Include microwave hybrid network to acquire V, H and ±45 degree linear (P/M) polarizations

# Overview of Cold Sky Tests

- Cold sky radiation is extremely stable at L-band for accurate radiometric calibration
- Five sets cold sky tests were completed from July 2005 through June 2006

| Date | Location | Center Frequency | Purpose and scope of tests |
|---|---|---|---|
| July 26-August 11, 2005 | JPL Bldg. 168 | 1.415 GHz | Initial tests of insertion loss and thermal control. Comparison with rectangular horn was performed to validate the analysis technique. Tests were also completed for various radome materials. |
| October 3-16, 2005 | JPL Bldg. 168 | 1.415 GHz | Tests with improved thermal control; Minor infrequent external radio frequency interference (RFI) was observed. |
| April 5-18, 2006 | JPL Mesa Antenna Range | 1.410 GHz and 1.415 GHz | Insertion loss tests at 1.410 GHz. Tests at 1.415 GHz were also performed to confirm measurements in October 2005 |
| April 24-May 11, 2006 | JPL Bldg. 168 | 1.410 GHz | In collaboration with the IIP team to study the impact of RFI. |
| May 23-June 19, 2006 | JPL Bldg. 168 | 1.410 GHz | Long term stability tests to determine the response of insertion loss to environmental parameters. |

# Insertion Loss Estimate from Cold Sky Measurements (July-August 2005)



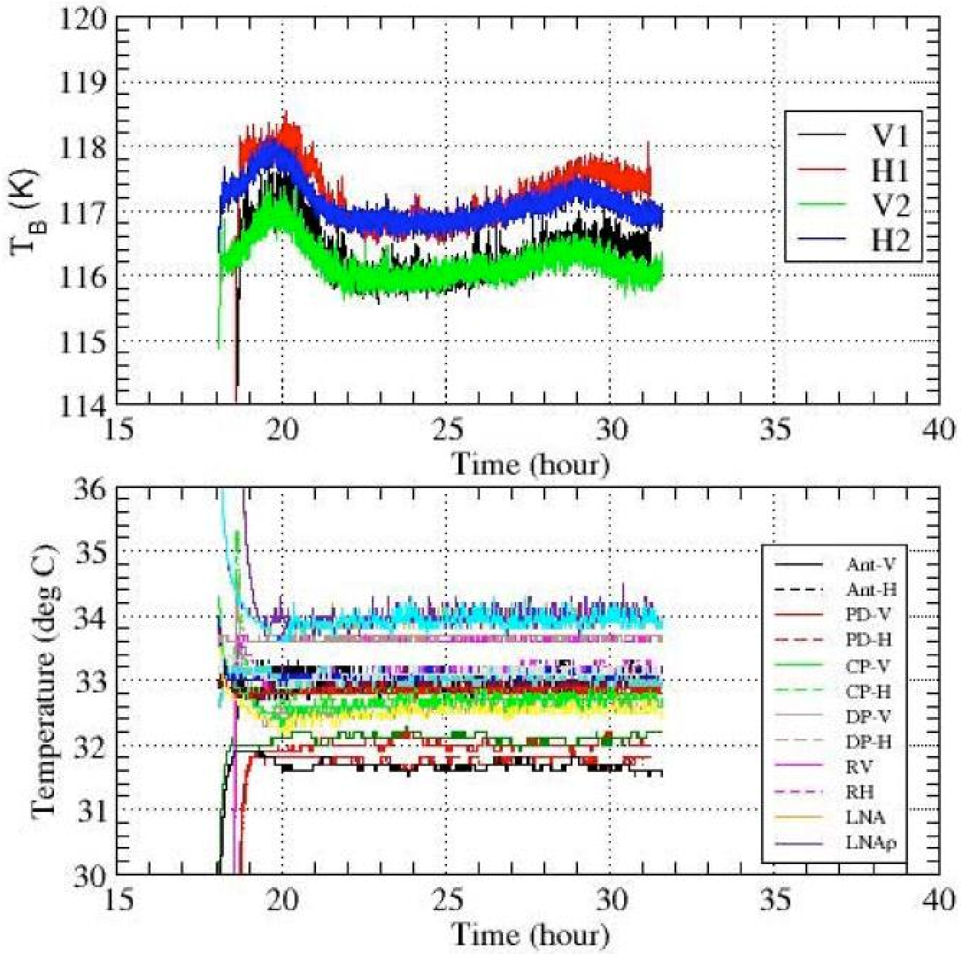

- The insertion loss of patch array is about 0.6 dB at 1.415 GHz

| **Parameter** | **Estimated Value (K)** |
|---|---|
| Measured zenith antenna temperature | 112 |
| Cold galactic background signal | ~ 6 |
| Backlobe pickup (~ 1.8 %) | ~ 5 |
| Reflected radiometer signal from horn (using measured -15 dB return loss) | ~ 10 |
| Calculated ACT antenna Ohmic emission | ~ 91 |

| | |
|---|---|
| Total insertion loss (measured) | 1.55 dB |
| Coaxial cable loss (measured) | 0.5 dB |
| Power divider loss (measured) | 0.4 dB |
| **Patch array loss** | **0.65 dB** |

# Results of Sky Testing Demonstrating Repeatability in October 2005

- Data acquired on Oct 8 and 9 showed strong repeatability (<0.2K) level over most parts of the night (before 3am).
- The difference increased to 0.5K level in early morning, probably caused by the varying backlobe pickup.
- There could be some small RFI on Oct 8.

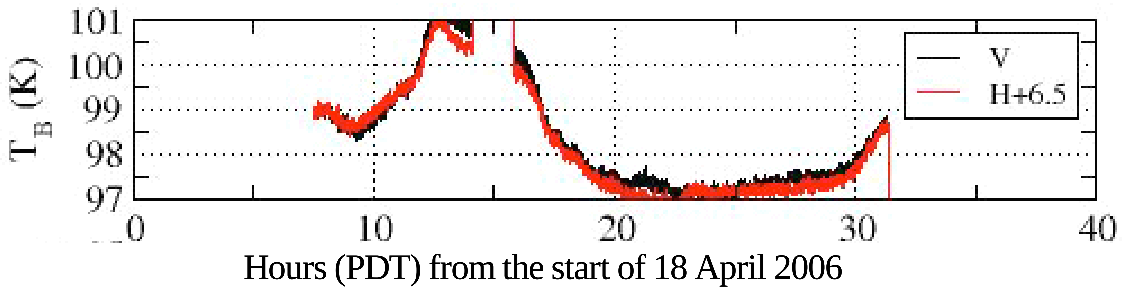


# Summary of Sky Tests at Mesa Antenna Range in April 2006 at 1.415 GHz

- The insertion loss of the patch array is about 0.64 dB, consistent with the rooftop test results in 2005.
- The standard deviation of the measurement is about 0.004 dB.

| Date | Tv (K) | Th (K) | Air Temperature (ºC) | Relative Humidity (%) | Total LV (dB) | Total LH (dB) | Array LV (dB) | Array LH (dB) |
|---|---|---|---|---|---|---|---|---|
| 4/5/2006 | 109.6 | 112 | 8.9 | 84.9 | 1.5123 | 1.5613 | 0.6123 | 0.6613 |
| 4/6/2006 | 110 | 112.4 | 11 | 83 | 1.5204 | 1.5695 | 0.6204 | 0.6695 |
| 4/7/2006 | 109.5 | 112 | 11.4 | 73.3 | 1.5103 | 1.5613 | 0.6103 | 0.6613 |
| 4/8/2006 | 109.6 | 112.3 | 12.3 | 78 | 1.5123 | 1.5675 | 0.6123 | 0.6675 |
| **Average (dB)** | | | | | **1.5138** | **1.5649** | **0.6138** | **0.6649** |
| **Standard Deviation (dB)** | | | | | **0.0045** | **0.0042** | **0.0045** | **0.0042** |

# Summary of Sky Tests at Mesa Antenna Range in April 2006 at 1.410 GHz




- The standard deviation of the insertion loss estimate is about 0.01 dB.
- The insertion loss at 1.410 GHz is about 0.55 dB, lower than that at 1.415 GHz by 0.1 dB

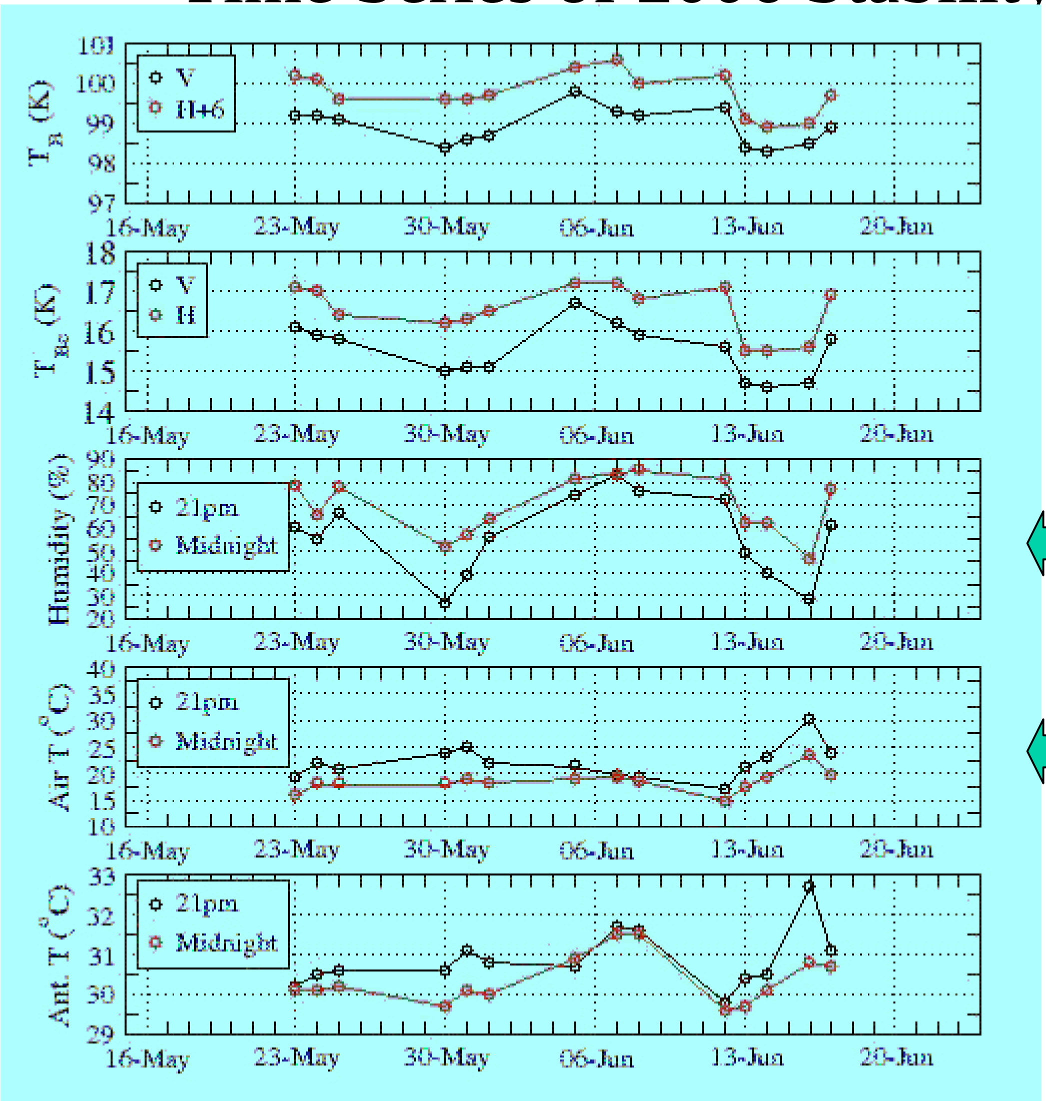
| Date | Tv (K) | TH (k) | Air Temperature (ºC) | Relative Humidity (%) | Array LV (dB) | Array LH (dB) |
|---|---|---|---|---|---|---|
| 4/11/2006 | 98.4 | 91.9 | 12.5 | 74.7 | 0.5578 | 0.5294 |
| 4/13/2006 | 98.4 | 91.7 | 16.7 | 54.5 | 0.5578 | 0.5255 |
| 4/15/2006 | 97.8 | 91.6 | 13.3 | 77.6 | 0.5458 | 0.5236 |
| 4/16/2006 | 97.8 | 91.4 | 13 | 77.8 | 0.5458 | 0.5197 |
| 4/17/2006 | 97.6 | 90.8 | 12.4 | 56 | 0.5418 | 0.5081 |
| 4/18/2006 | 97.1 | 90.6 | 17.7 | 35.4 | 0.5319 | 0.5042 |
| **Average (dB)** | | | | | **0.5468** | **0.5184** |
| **Standard Deviation (dB)** | | | | | **0.0099** | **0.0101** |

# Stability Test Data at 1.410 GHz from May 23-June 19, 2006

| Date | Tv (K) | Th (K) | Air Temperature (ºC) | Humidity (%) | Antenna Surface Temperature (ºC) | Array LV (dB) | Array LH (dB) |
|---|---|---|---|---|---|---|---|
| 5/23/2006 | 99.2 | 94.2 | 16 | 78.4 | 30.1 | 0.5418 | 0.5431 |
| 5/24/2006 | 99.2 | 94.1 | 18 | 65.8 | 30.1 | 0.5418 | 0.5411 |
| 5/25/2006 | 99.1 | 93.6 | 18 | 78 | 30.2 | 0.5398 | 0.5314 |
| 5/30/2006 | 98.4 | 93.6 | 18 | 51 | 29.7 | 0.5259 | 0.5314 |
| 5/31/2006 | 98.6 | 93.6 | 19 | 57 | 30.1 | 0.5299 | 0.5314 |
| 6/1/2006 | 98.7 | 93.7 | 18.3 | 63.9 | 30 | 0.5319 | 0.5333 |
| 6/5/2006 | 99.8 | 94.4 | 18.8 | 81.4 | 30.9 | 0.5538 | 0.5470 |
| 6/7/2006 | 99.3 | 94.6 | 19.2 | 84.2 | 31.5 | 0.5438 | 0.5509 |
| 6/8/2006 | 99.2 | 94 | 18.7 | 85.3 | 31.5 | 0.5418 | 0.5392 |
| 6/12/2006 | 99.4 | 94.2 | 14.8 | 81.2 | 29.6 | 0.5458 | 0.5431 |
| 6/13/2006 | 98.4 | 93.1 | 17.6 | 62 | 29.7 | 0.5259 | 0.5217 |
| 6/14/2006 | 98.3 | 92.9 | 19.3 | 62.2 | 30.1 | 0.5239 | 0.5178 |
| 6/16/2006 | 98.5 | 93 | 23.5 | 46.2 | 30.8 | 0.5279 | 0.5197 |
| 6/17/2006 | 98.9 | 93.7 | 19.8 | 77.1 | 30.7 | 0.5358 | 0.5333 |
| 6/19/2006 | 98.8 | 93.7 | 19.5 | 70.2 | 30.3 | 0.5338 | 0.5333 |
| **Average (dB)** | | | | | | **0.5362** | **0.5345** |
| **Standard Deviation (dB)** | | | | | | **0.0087** | **0.0098** |

- Tests conducted on the rooftop of JPL Bldg 168
- Temperature sensor installed on the front face of MSPA to monitor the antenna surface temperature
- The insertion loss estimate is about 0.53 dB±0.01dB

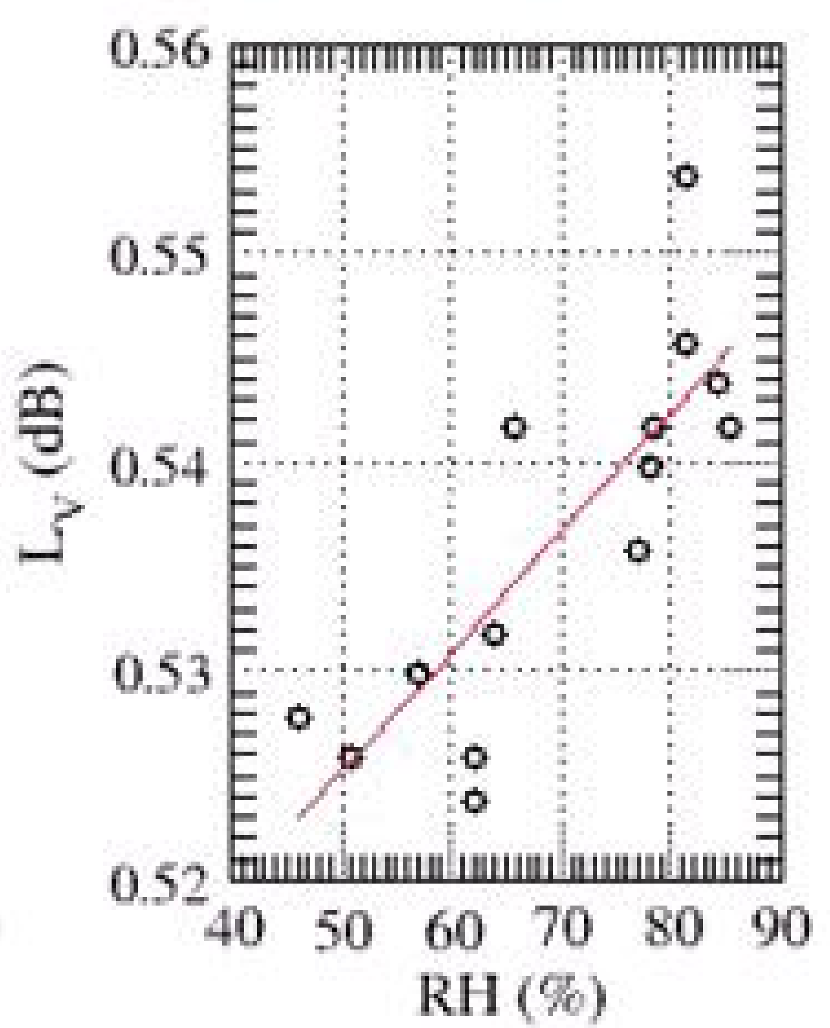
# Time Series of 2006 Stability Test Data





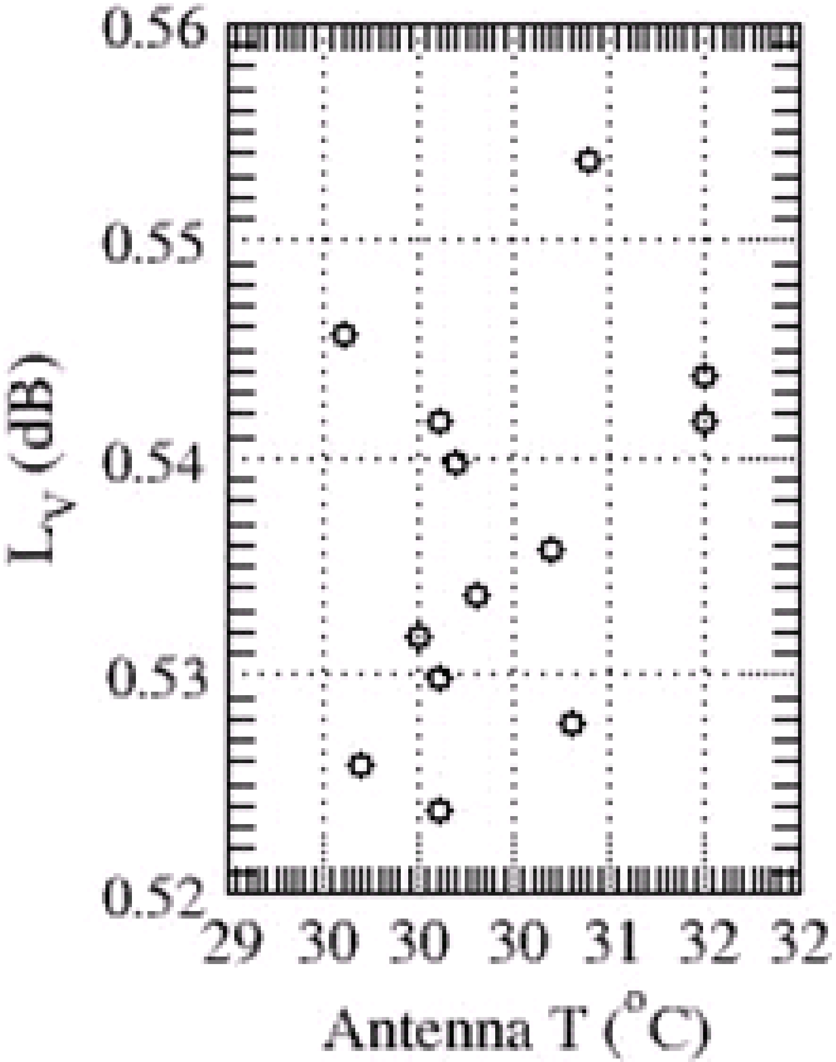
- There was correlation with relative humidity.
- No obvious correlation with air temperature and antenna surface temperature

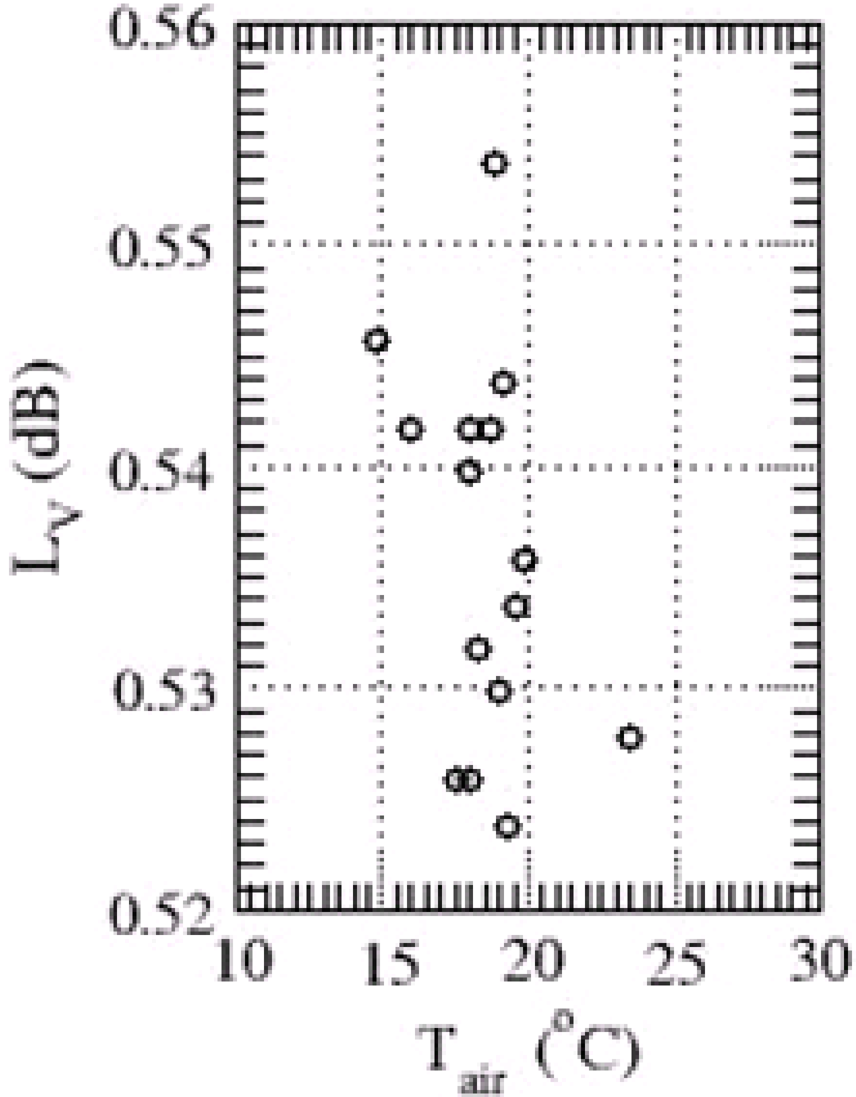
Strong Correlation with Relative Humidity




- Strong correlation with ambient relative humidity
  - 0.81 correlation for V-pol
  - 0.74 correlation for H-pol
- The standard deviation from the linear regression
  - 0.005 dB for V-pol
  - 0.007 dB for H-pol

# No Obvious Correlation with Temperature



# Summary of Cold Sky Tests

- The insertion loss of the MSPA has strong correlation with the relative humidity from the JPL weather station data
- No obvious correlation with the air temperature or antenna surface temperature
- The insertion loss estimates are about 0.5±0.005 dB at 1.410 GHz.

# Assessment Against Soil Moisture and Salinity Mission Requirements

- ✓ Three frequency design to accommodate Hydros requirements (1.26, 1.29 and 1.41 GHz)
  - – Aquarius requires only 1.26 and 1.41 GHz channels
- ✓ Dual-polarization with high polarization isolation (>30 dB)
- ✓ High radiometric calibration stability (Low insertion loss and temperature control requirement) for soil mositure

| | Frequency | Polarization | Polarization Isolation | Radiometer Calibration | Radar Calibration |
|---|---|---|---|---|---|
| Hydros | 1.26, 1.29, and 1.413 GHz | Polarimetric (H and V polarizations for antenna) | >25 dB | 0.7 K | 0.3 dB |
| Aquarius | 1.26 and 1.413 GHz | Polarimetric | >25 dB | 0.1 K | 0.1 dB |
| MSPA/PALS | Requirement met | Requirement met | Requirement met | <0.3 K (ground measurement) | Requirement met (0.005 dB) |

# Conclusions

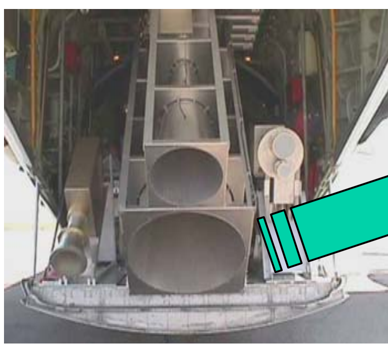
- It has been demonstrated that the performance of the MSPA feed will meet the soil moisture mission requirement
  - The stability of the MSPA loss is better than 0.005 dB and 0.3K
  - Required additional work to demonstrate the performance for salinity missions

# Future Plan for MSPA/PALS-II

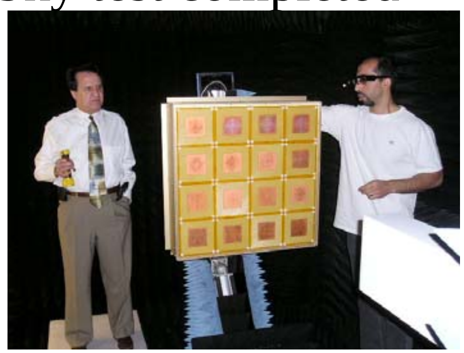
By July 2006 — Summer 2007

**NCAR C-130 aircraft used for PALS Mission**

**Passive Active L/S-band (PALS) Instrument on the C-130 aircraft**



- Full array completed and tested in Jan 2005
- Greater than 35 dB polarization isolation
- Sky test completed



- Polarimetric upgrade completion in 2005

- Planning science field experiments on Twin-Otter

Twin Otter

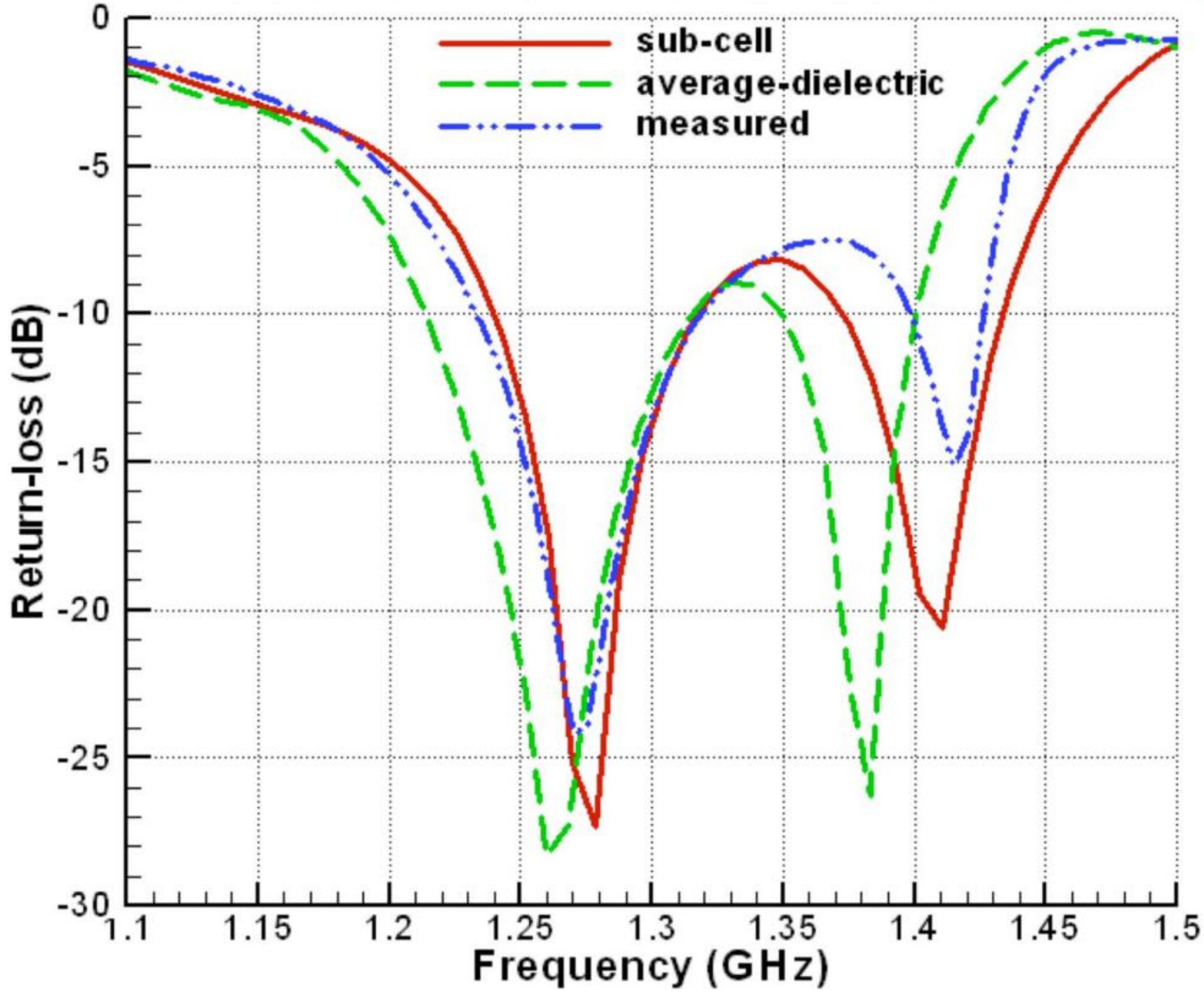
- **Proposal for field experiment selected for support under the NEWS program**

# Future Work

- Conduct additional ground tests to minimize the impact of moisture to assess the calibration performance of the MSPA for salinity measurements

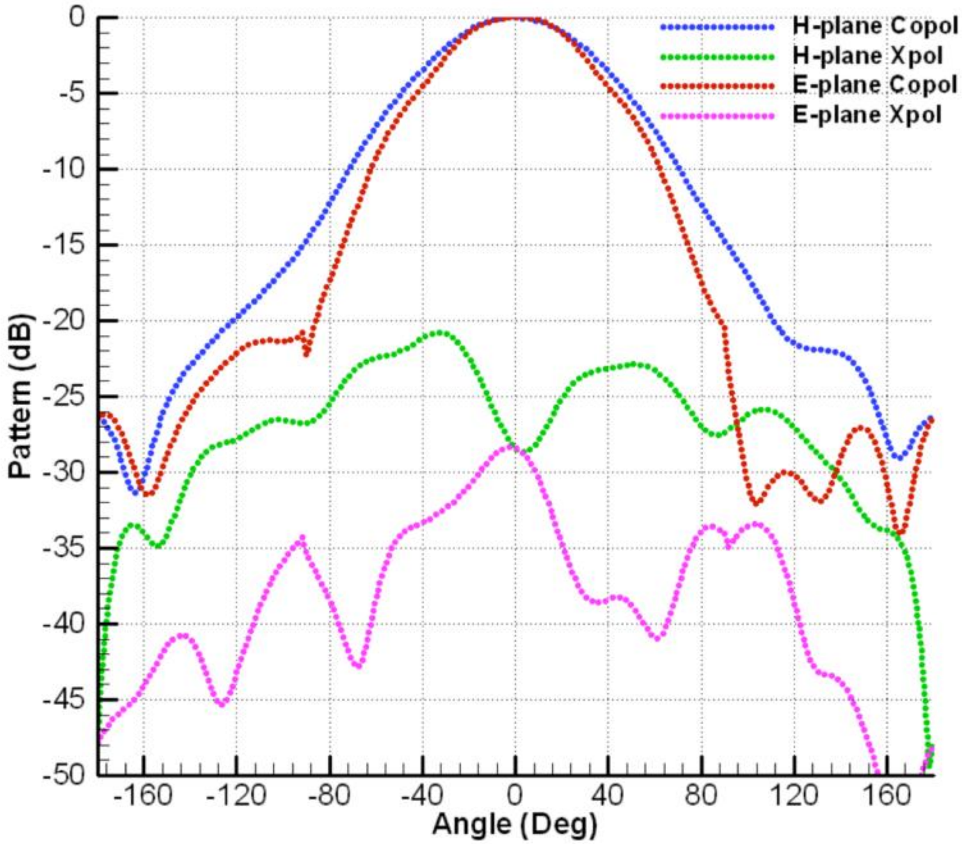
Backup Charts

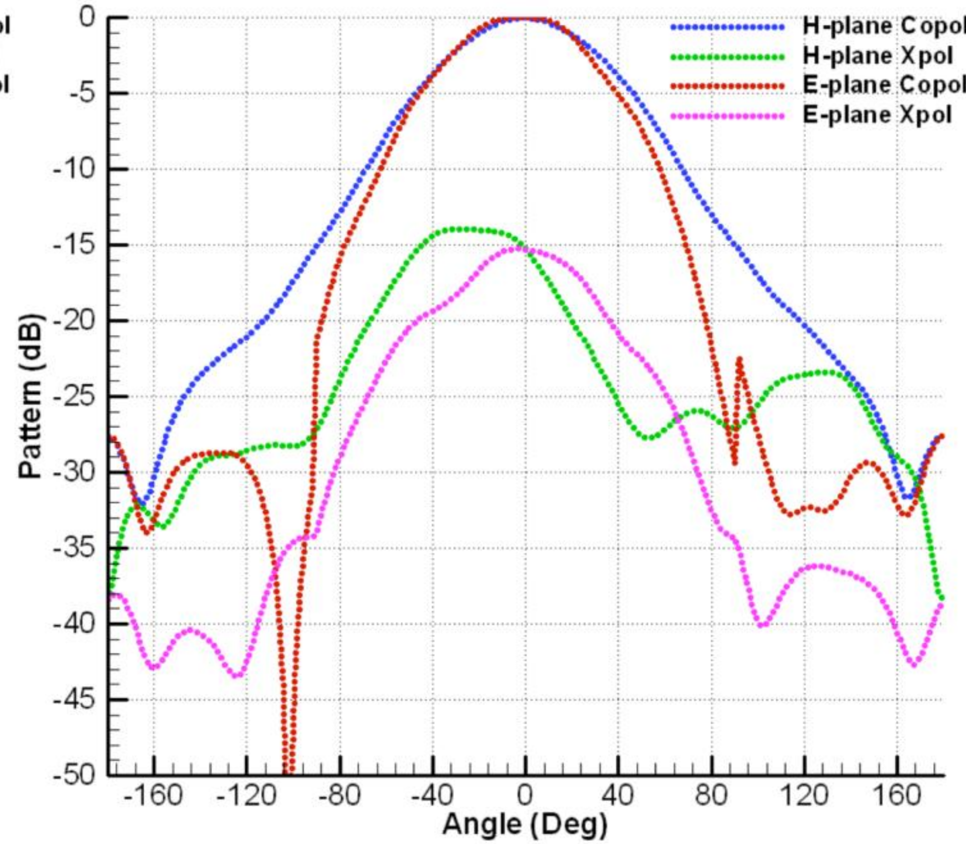
# Return-Loss Results for the Stacked patch Element




Comparison between Return-loss for Sub-cell, Weighted Average FDTD Simulations and Measured results

# Measured Radiation Pattern for Stacked Patch Element (Spherical Near-Field Measurement Chamber : UCLA)



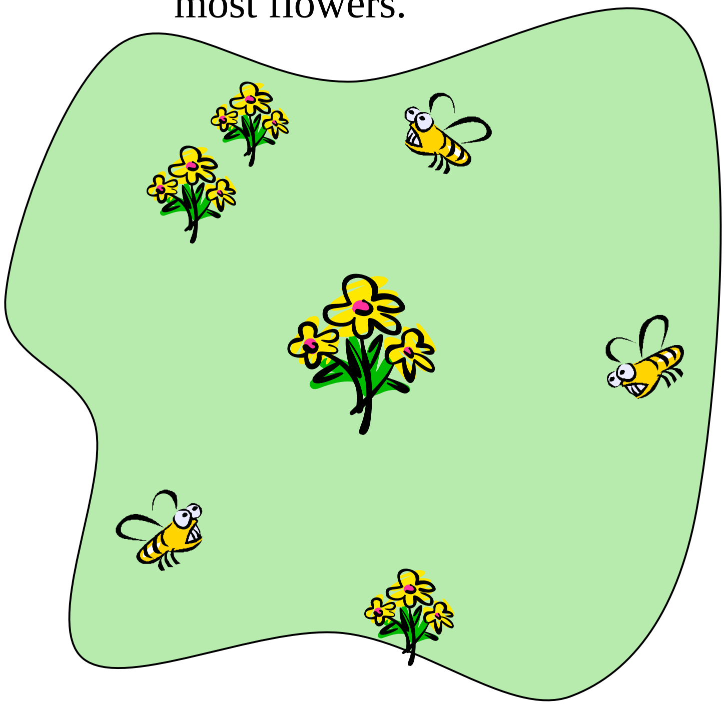




Measured Radiation pattern lower frequency (1.26GHz)

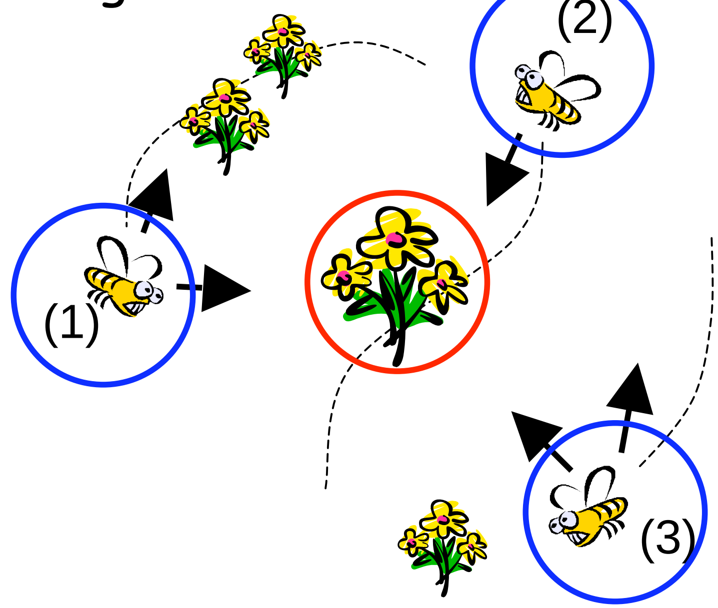
Measured Radiation pattern upper frequency (1.413GHz)

# Particle Swarm Optimization (PSO)

Consider a swarm of bees that want to find the area with the most flowers.



- PSO models the behavior of natural swarms.
- The position of each "particle" represents a possible solution.
- Particles move toward locations that have had good results.




## Particle-Swarm Algorithm

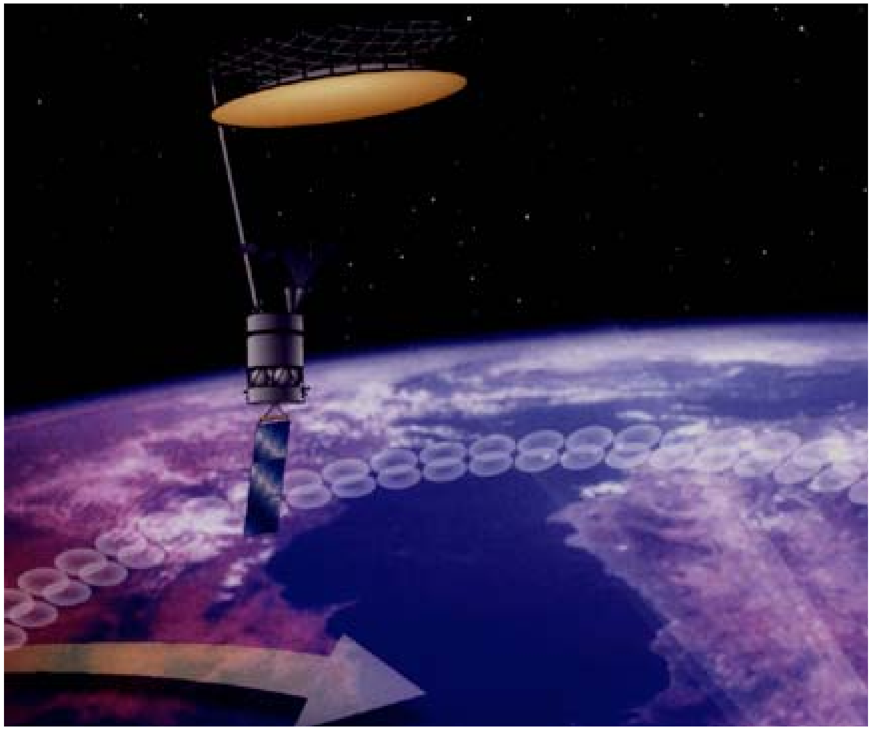
- **(1) Found a personal best location.**
  - **One component of the velocity vector points to that position.**
  - **The other vector component points to the global best position**
- **(2) Found global best location.**
- **(3) No useful personal best location**

# Fitness Calculation

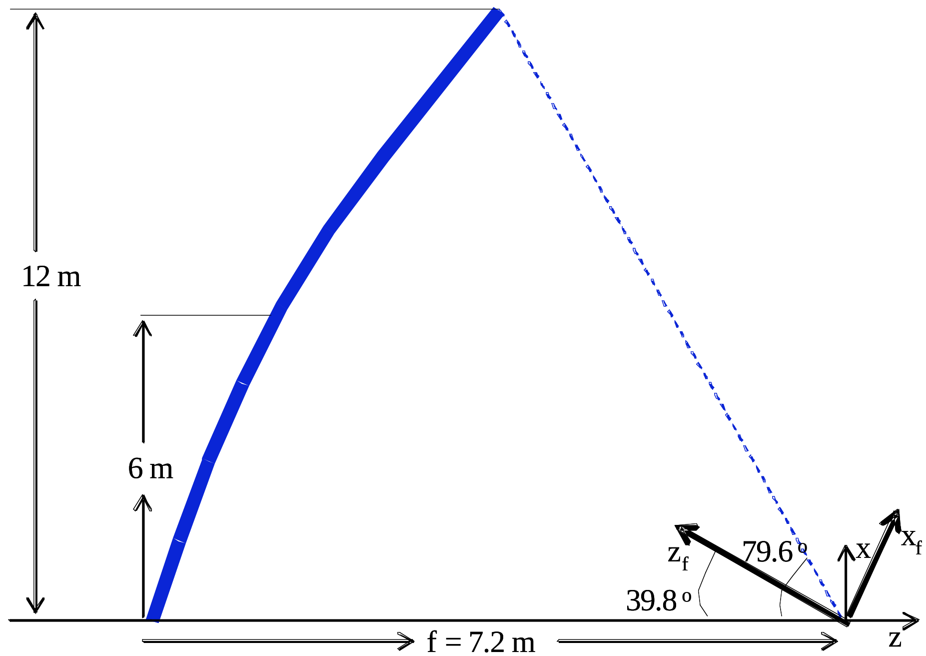
| | |
|---|---|
| (1) Position vector from PSO: | $\vec{x} = \{d, I_0, I_1, I_2, I_3\}$ |
| (2) Reformat for 16 elements: | $\mathbf{I} = \{I_0, ..., I_{15}\}$<br>$\mathbf{X} = \{x_1, ..., x_{15}\}$<br>$\mathbf{Y} = \{y_1, ..., y_{15}\}$ |
| (3) Find total radiated power from DUAL: | $P_{\text{total}}$ |
| (4) Find HPBW from far-field pattern: | HPBW |
| (5) Radiated power from $0 < \theta < 1.25 \times \text{HPBW}$ | $P_{\text{beam}}$ |
| (6) Calculate fitness value: | $F = \left(100 - 100\frac{P_{\text{beam}}}{P_{\text{total}}}\right)^2$ |

# Potential L-band Array Topologies as Feed for 12m Offset Reflector (Simulations)

# Proposed 12m Offset Reflector Antenna Geometry



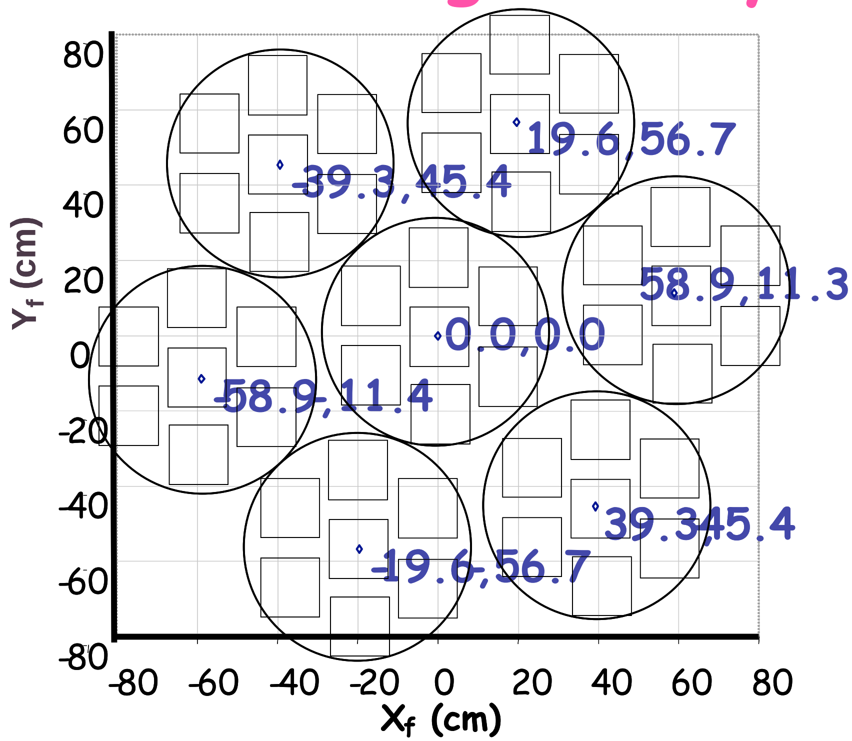
Artist's rendering of an offset paraboloidal reflector antenna with a deployable mesh reflector and multiple reflector feeds.
(Only two beams of the planned seven beams are shown in the figure)




Vertical cross section of the desired offset parabolic reflector antenna

Reflector Geometry: Antenna diameter of 12 m
Focal length of 7.2 m.
Feed for the reflector is offset by 6 m.
Subtended angle of the reflector is 79.6°.

# View of the geometry of the planned seven feeds



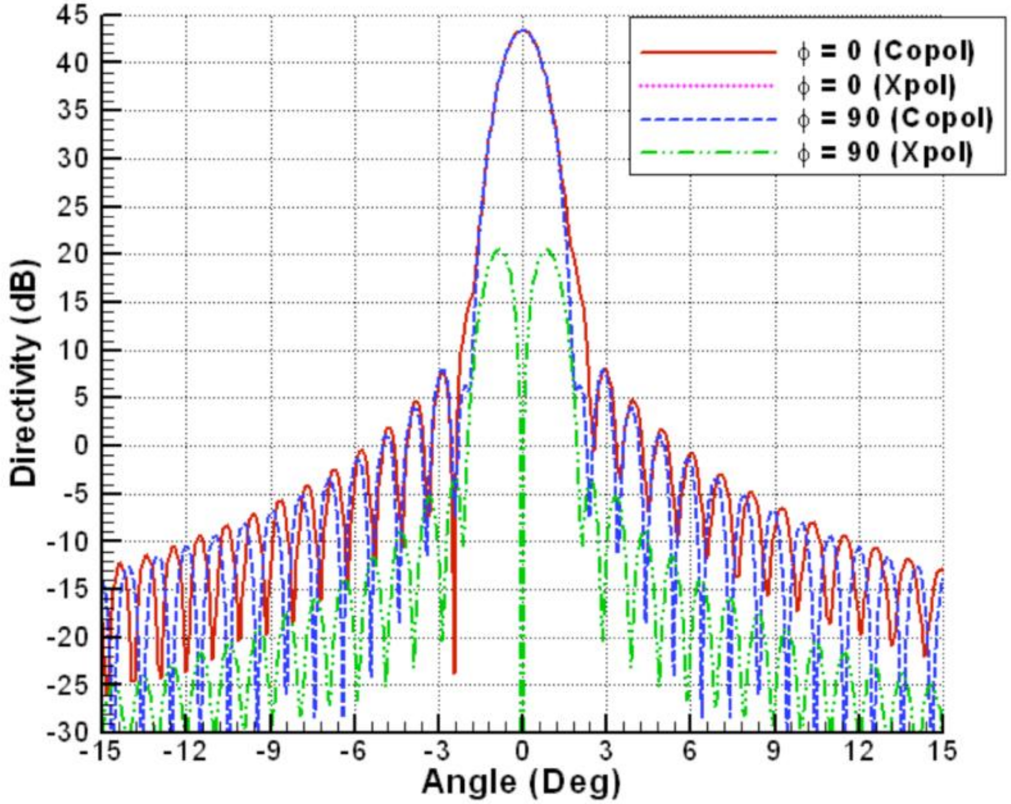

Feed Geometry for the reflector system. Each point represents the center of each feed.

| Feed | $X_f$ (cm) | $Y_f$ (cm) |
|---|---|---|
| 0 | 0.0 | 0.0 |
| 1 | 19.6 | 56.7 |
| 2 | 58.9 | 11.3 |
| 3 | 39.3 | -45.4 |
| 4 | -19.6 | -56.7 |
| 5 | -58.9 | -11.4 |
| 6 | -39.3 | 45.4 |

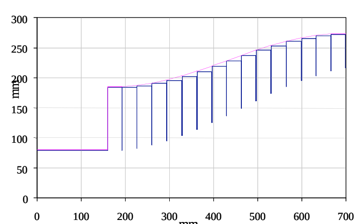
Coordinates of all seven feeds with respect to the focus of the reflector

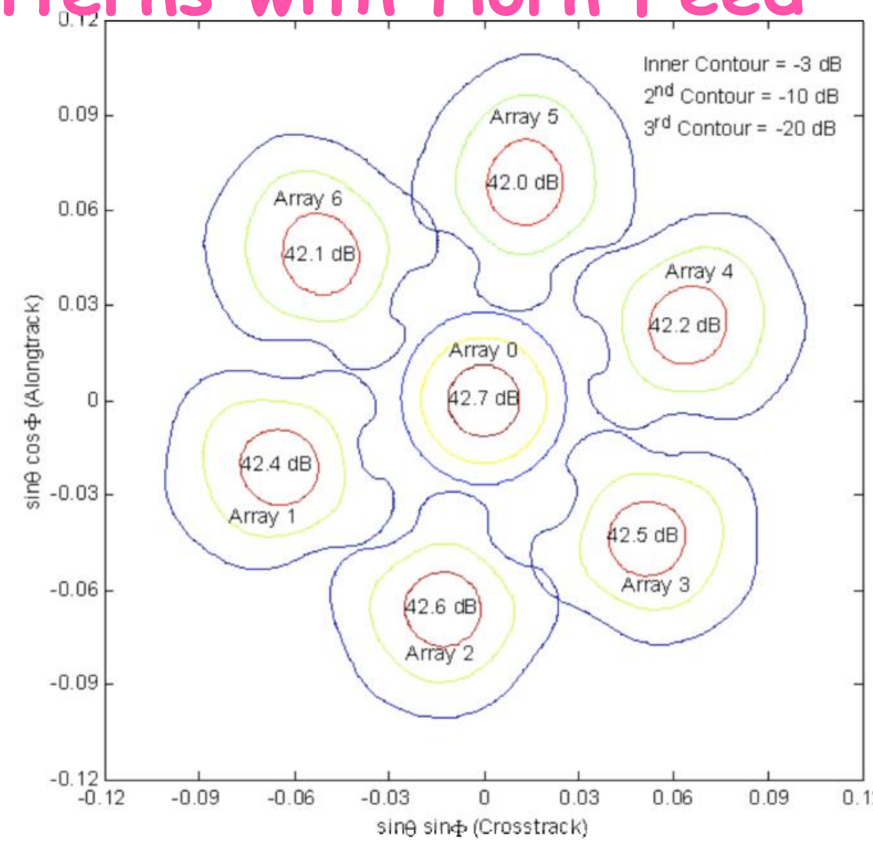
Remarks: There will be seven feeds located near the focus of the antenna. One feed is directly at the focus of the antenna with the other six feeds forming a ring around the feed at the focus. The center of the offset feeds will be 60 cm from the focus.

# 12m Offset Reflector Patterns with Horn Feed




Far field reflector pattern illuminated by a horn with the feed located at the focus of the 12 m reflector antenna operating at the L-band frequency of 1.413 GHz.



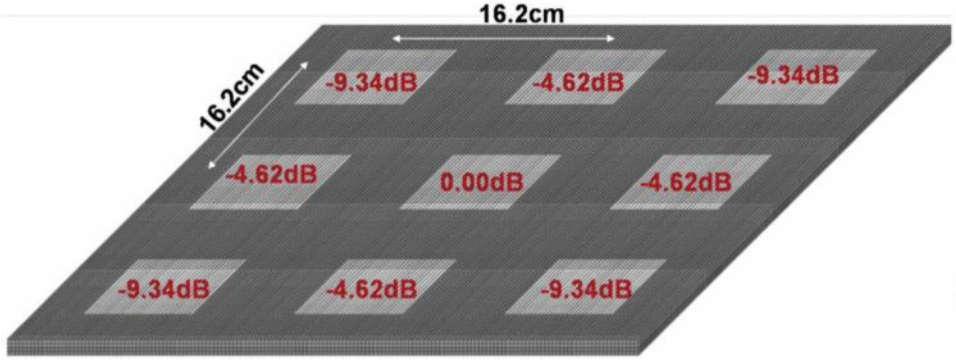




Far-field footprint of seven corrugated horn feeds illuminating the 12 m reflector antenna at 1.413GHz. Contours are -3 dB, -10 dB, and -20 dB below the peak of each beam.

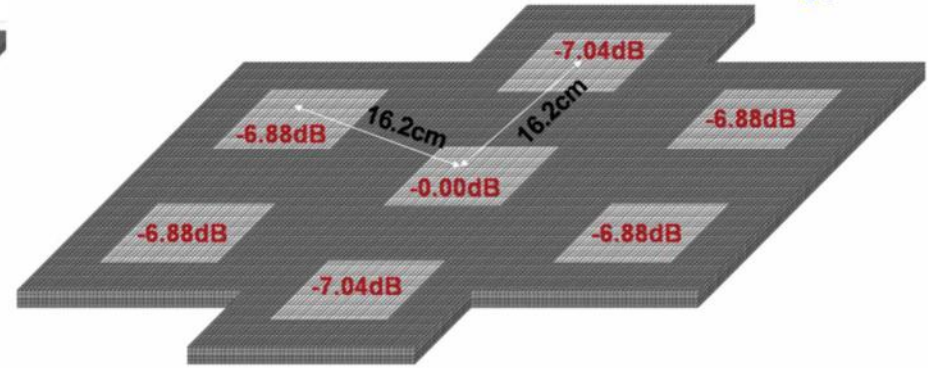


An alternative design to horn feeds is using patch arrays as feed to illuminate the reflector.

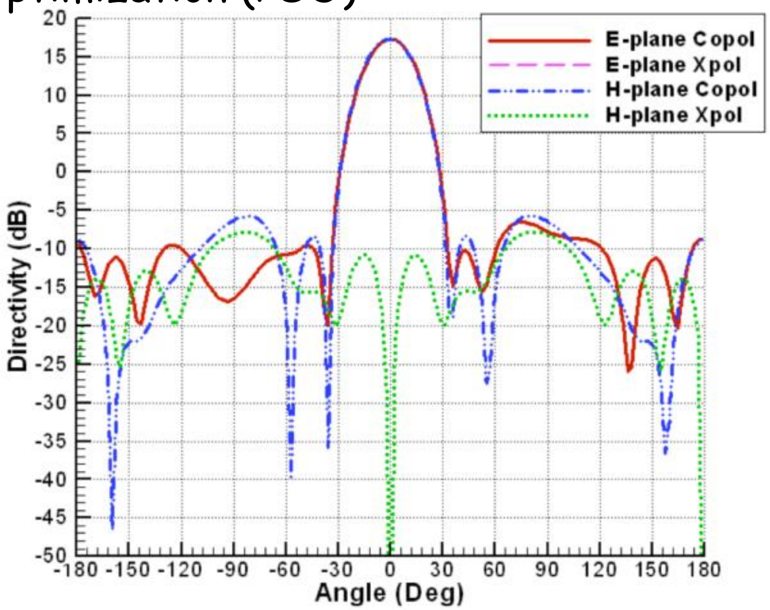
# Study of array topologies using FDTD Simulations as alternative feeds to horns



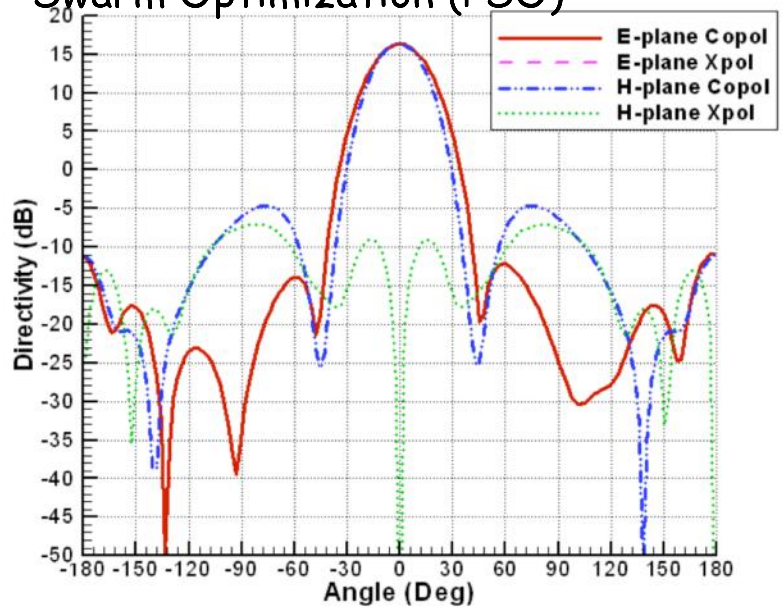

FDTD mesh model showing nine-element square array excitation amplitudes optimized using Particle Swarm Optimization (PSO)




FDTD mesh model showing seven-element hexagonal array excitation amplitudes optimized using Particle Swarm Optimization (PSO)




FDTD simulated far-field pattern (Nine-element square array)




FDTD simulated far-field pattern (Seven-element hexagonal array)

JPL

UCLA

# Tabulated Results of single element and comparison of array and horn feeds

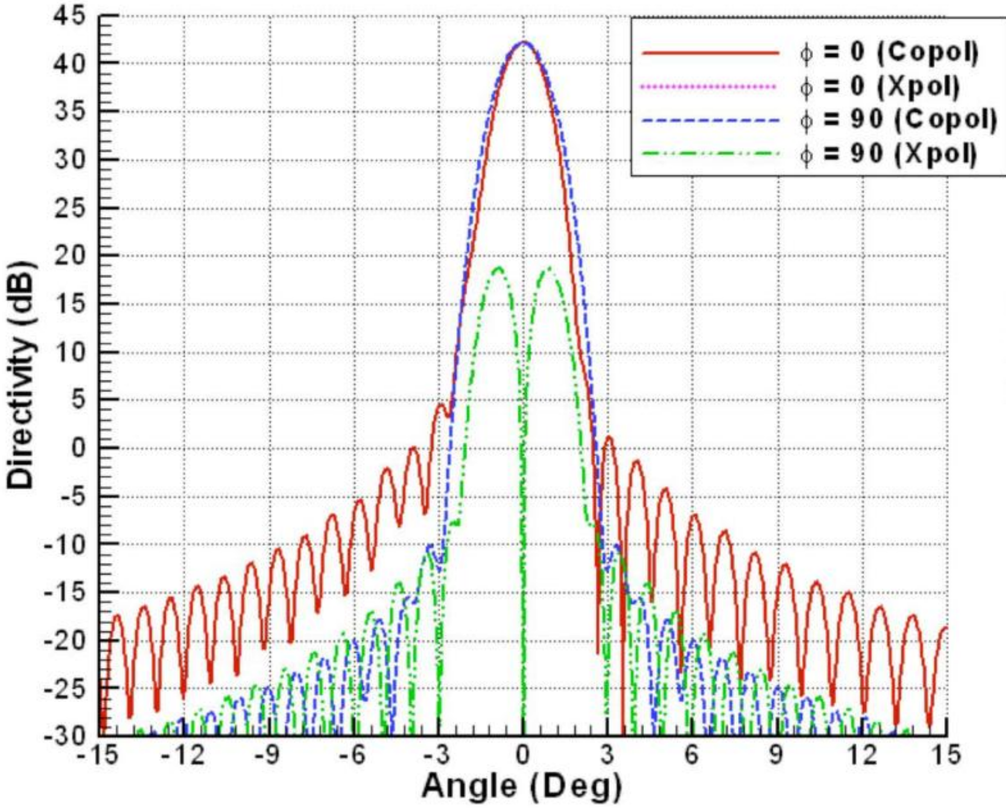
## Single Patch Geometry and Impedance Specifications

| | Length (cm) | Substrate $\epsilon_r$, $\tan\delta$ | $S_{11}$ (dB) | Bandwidth |
|---|---|---|---|---|
| Radar (1.26 GHz) | 9.10 | 1.52, 0.0004 | -23 | ±10MHz |
| Radiometer (1.413 GHz) | 8.50 | 1.32, 0.0003 | -30 | ±15MHz |

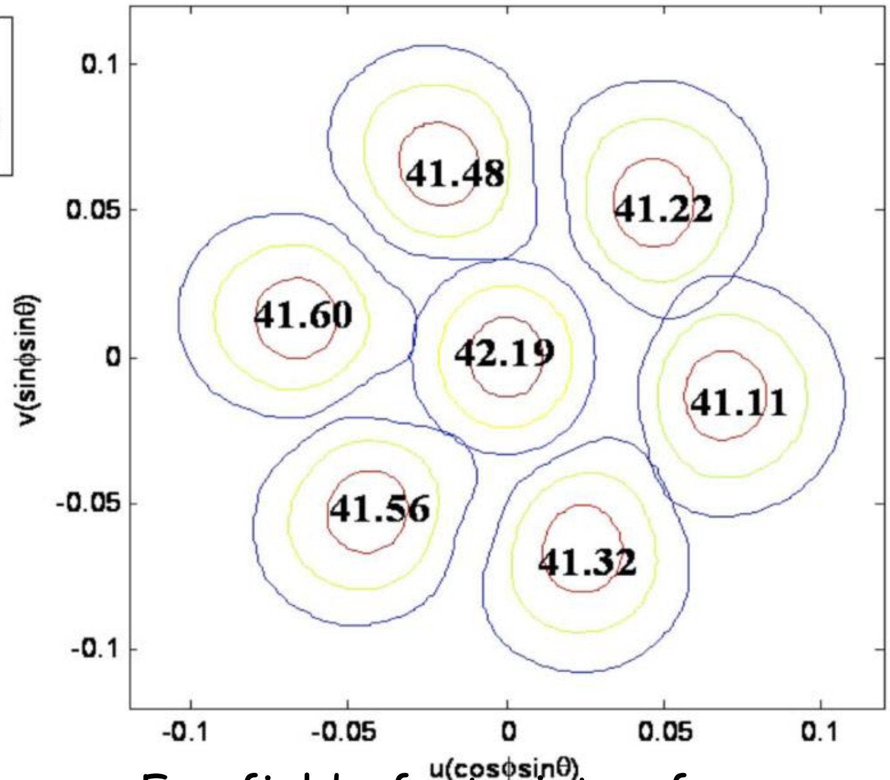
## Comparison of far-field radiation results of the various feeds

| Feed | Directivity (dB) | 3dB beamwidth (E-plane) | 3dB beamwidth (H-plane) |
|---|---|---|---|
| Horn | 15.20 | 34.0° | 34.0° |
| 7 –element hex-array | 16.29 | 31.7° | 27.9° |
| 9-element square-array | 17.25 | 26.7° | 27.0° |

# 12m Offset Reflector Patterns with Hexagonal Array Feed



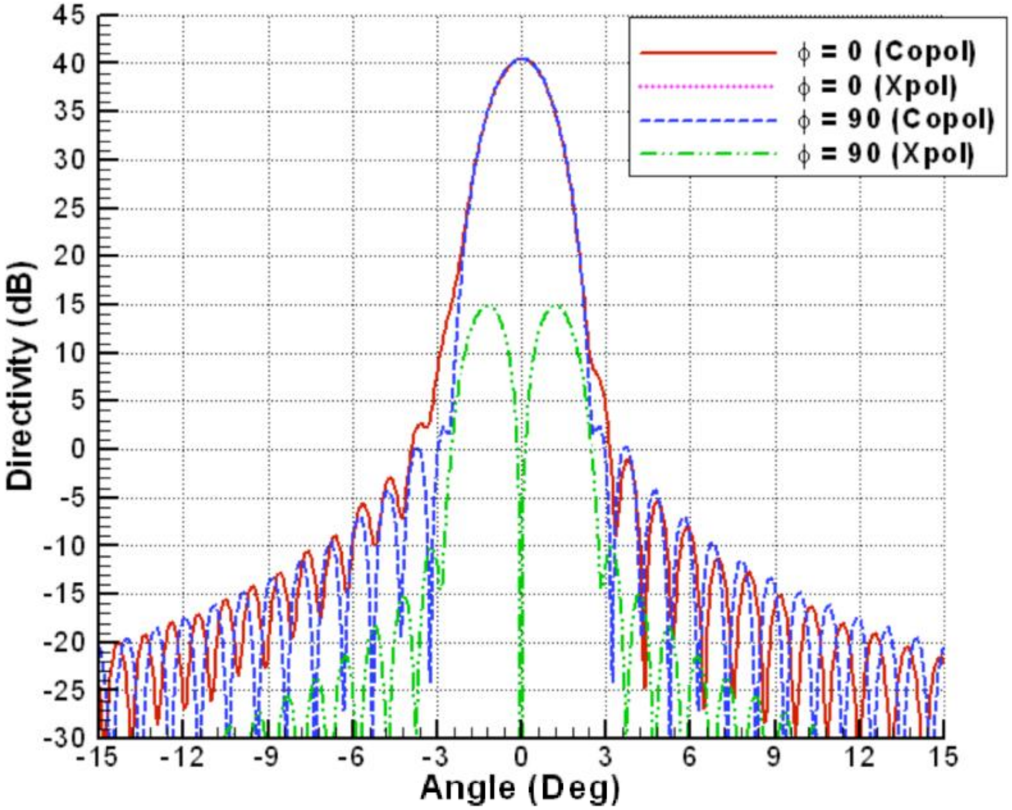

Far field reflector pattern illuminated by seven-element hexagonal array with the feed located at the focus of the 12 m reflector antenna operating at the L-band frequency of 1.413 GHz.



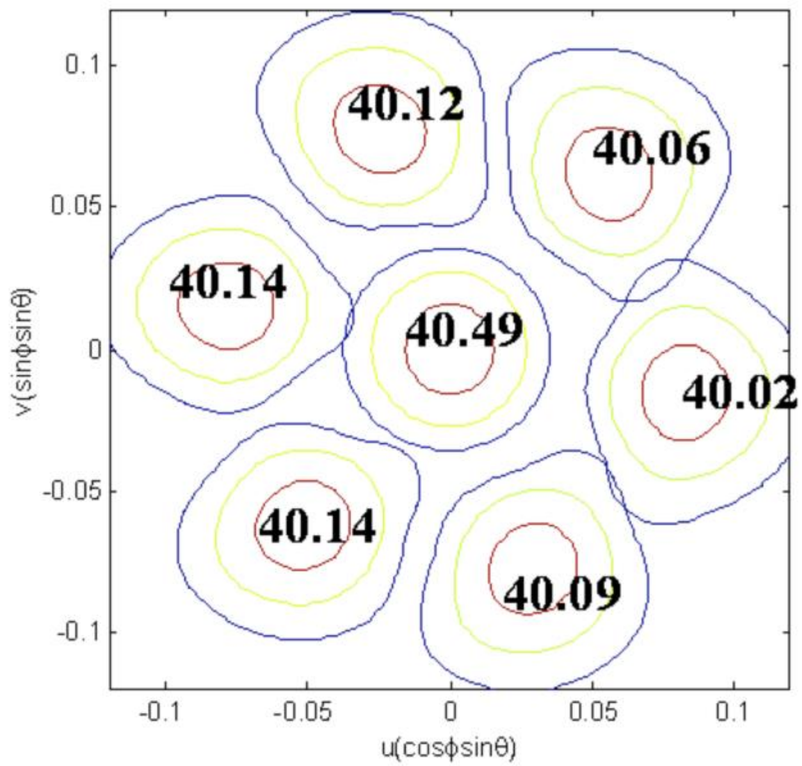

Far-field footprint of seven seven-element hexagonal feeds illuminating the 12 m reflector antenna at 1.413 GHz. Contours are -3 dB, -10 dB, and -20 dB below the peak of each beam.

JPL

# 12m Offset Reflector Patterns with Square Array Feed




Far field reflector pattern illuminated by seven-element hexagonal array with the feed located at the focus of the 12 m reflector antenna operating at the L-band frequency of 1.413 GHz.




Far-field footprint of seven nine-element square feeds illuminating the 12 m reflector antenna at 1.413 GHz. Contours are -3 dB, -10 dB, and -20 dB below the peak of each beam.

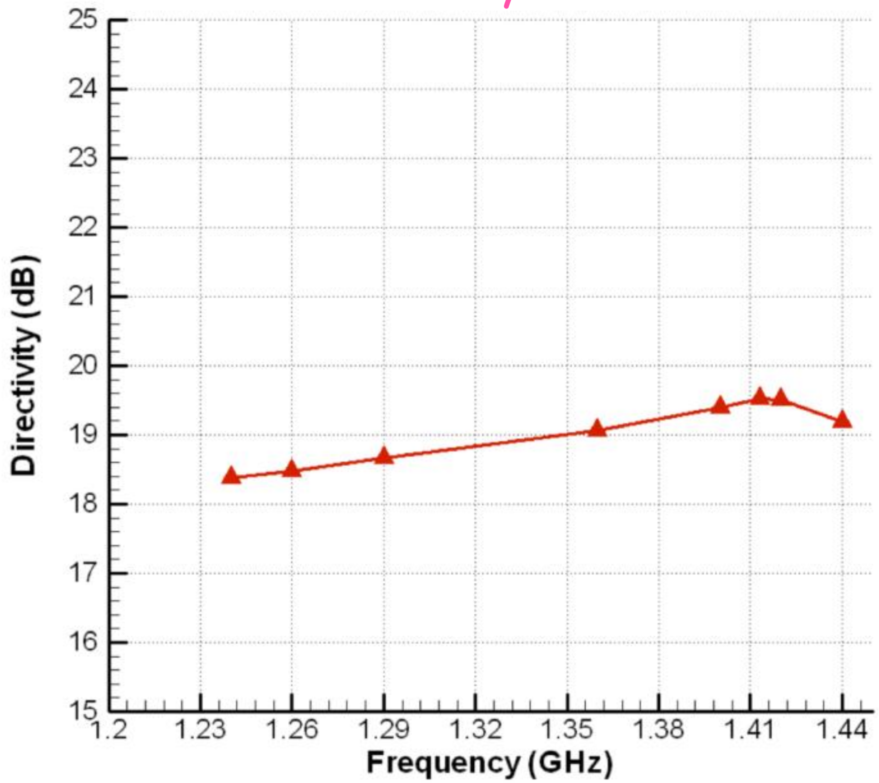
# Comparison of far-field radiation results with various feeds for 12 m offset reflector

| Feed | Directivity (dB) | Beam-efficiency (%) | 3dB beamwidth |
|---|---|---|---|
| Horn | 42.0 | 96.1% | $1.30^{o}$ |
| 7-element hex-array | 42.19 | 94.25% | $1.46^{o}$ |
| 9-element square-array | 40.49 | 93.64% | $1.84^{o}$ |

* With respect to the 3 dB beamwidth when the feed is located at the reflector's focus

# Summary of Measured Results

# Measured Directivity and Estimated Beam-Efficiency of the 16-element Array




| Frequency (GHz) | Measured Directivity (dB) |
|---|---|
| 1.24 | 18.375 |
| 1.26 | 18.477 |
| 1.29 | 18.675 |
| 1.36 | 19.072 |
| 1.40 | 19.395 |
| 1.413 | 19.522 |
| 1.42 | 19.517 |
| 1.44 | 19.195 |

## Estimation of Beam-Efficiency from Measured Results (Frequency: 1.413GHz)

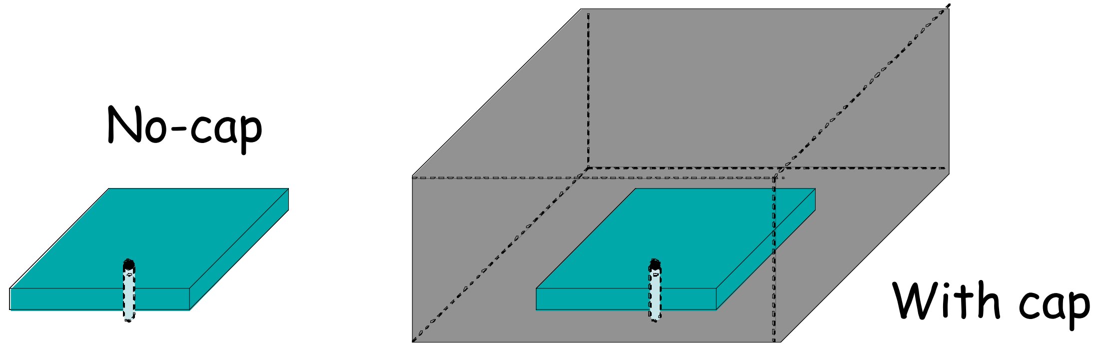
| Port | Beam-efficiency (E-plane beamwidth) | Beam-efficiency (H-plane beamwidth) | Beam-efficiency (Average) | Directivity (dB) |
|---|---|---|---|---|
| H-port | 94.20% | 94.50% | 94.20% | 19.61 |
| V-port | 94.00% | 94.35% | 94.35% | 19.52 |

# Antenna characteristics from measurement

| Parameter | Measurement<br>Lower Patch | <br>Upper Patch |
|---|---|---|
| Resonant Frequency (GHz) and frequency bands (MHz) | 1.26±10 | 1.413±15 |
| Directivity (dB) | 18.47 | 19.53 |
| 3dB Beamwidth (HPBW) (Degrees) | E-plane: 22.87<br>H-plane: 23.00 | E-plane: 20.10<br>H-plane: 20.41 |
| 1st Side-lobe level (dB) | -22.00 | -24.00 |
| Cross-polarization levels (dB) (principle planes) | <-40.0 | <-40.0 |
| Beam-efficiency (%) (Freq: 1.413GHz) | N/A | 94.3 |

# Estimation of Loss and Efficiency of L-band Array

# FDTD Implementation of Wheeler Cap




Schematic of probe-fed single resonance microstrip antenna with no cap and with conducting cap

Procedure for FDTD Implementation of Wheeler Cap:

- Two simulations of input impedance of the antenna.
- Simulation 1: Antenna is isolated and is allowed to radiate into free space (PML boundary condition in FDTD).
- Simulation 2: Antenna is enclosed in a conducting metal cap (PEC in FDTD)
- Input resistance of antenna in isolated state : $R_r+R_l$

Input resistance of the antenna with a cap: $R_l$

($R_r$ is the radiation resistance, $R_l$ is the loss resistance)

- Efficiency:

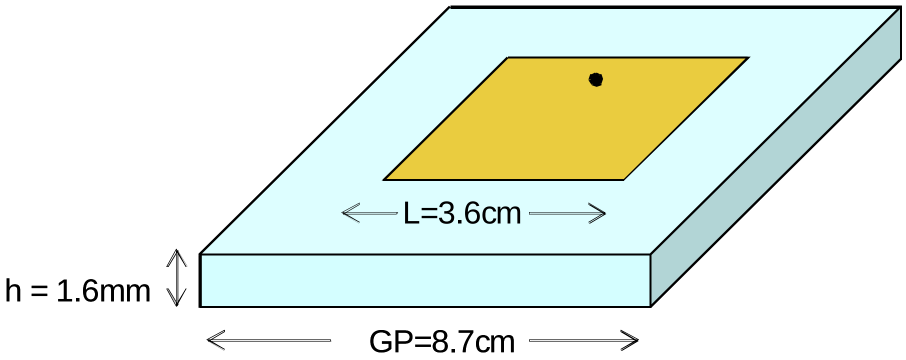
$$Eff = \frac{R_{no\_cap} - R_{cap}}{R_{no\_cap}}$$

Series RLC Equivalent

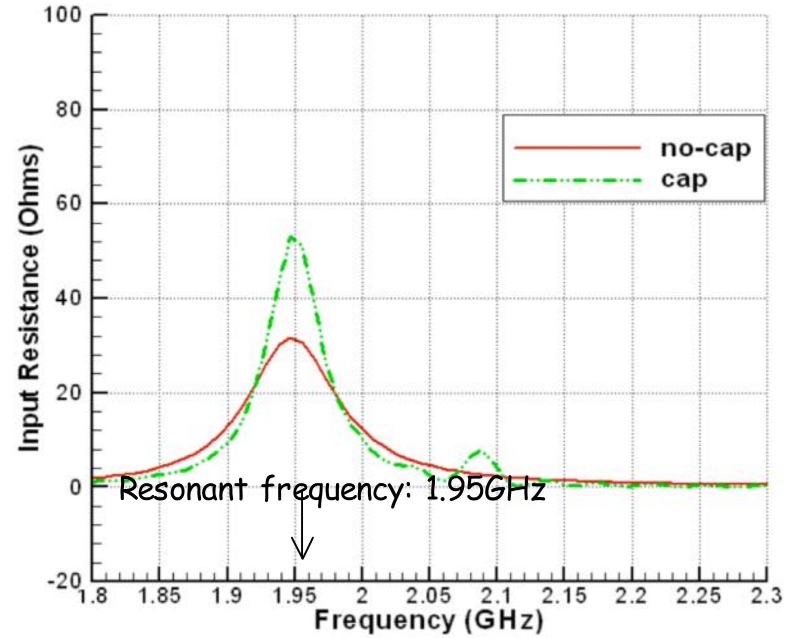
$$Eff = \frac{G_{no\_cap} - G_{cap}}{G_{no\_cap}}$$

Parallel RLC Equivalent

# FDTD Validation of Wheeler Cap for High-Loss Substrate




Microstrip geometry with high-loss FR-4 substrate ($\epsilon_r$= 4.1, tanδ=0.025)




Input resistance computed from FDTD

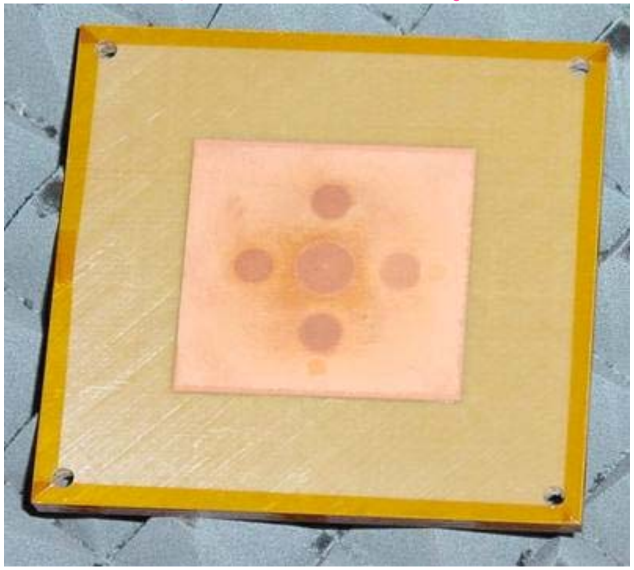
## Efficiency:

$$Eff = \frac{\frac{1}{31.75} - \frac{1}{53.05}}{\frac{1}{31.75}} \% = 40.15\%$$

Efficiency computed from reference is 41.0% using commercial software ENSEMBLE

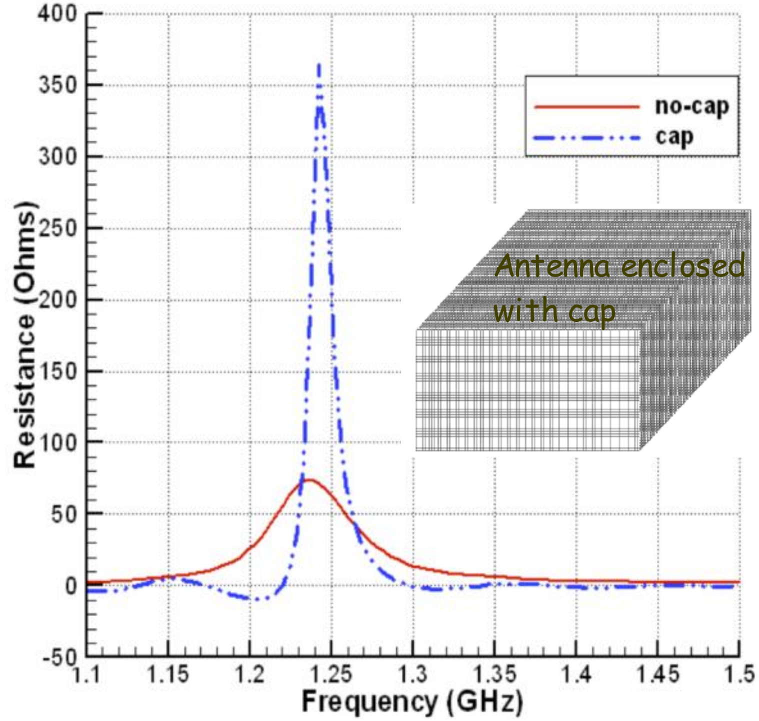

Ref: H. Choo, H. Ling, "On the Wheeler Cap Measurement of the Efficiency of Microstrip Antennas" *IEEE Trans. Antennas Propagation,* Vol. 53, No. 7, pp. 2328- 2332, July 2005.

# FDTD simulation of Wheeler Cap for low-loss L-band substrate



L-band stacked patch element

Patch size: 9.0cm x 9.0cm,
Ground-plane size: 16.2cm x 16.2cm
Substrate ($\epsilon_r$= 1.52, tan$\delta$=0.00383)
Cap dimensions: 22.4cm x 7.2cm x 22.4cm




Input resistance with cap: 322.91Ω

Input resistane without cap: 23.99Ω

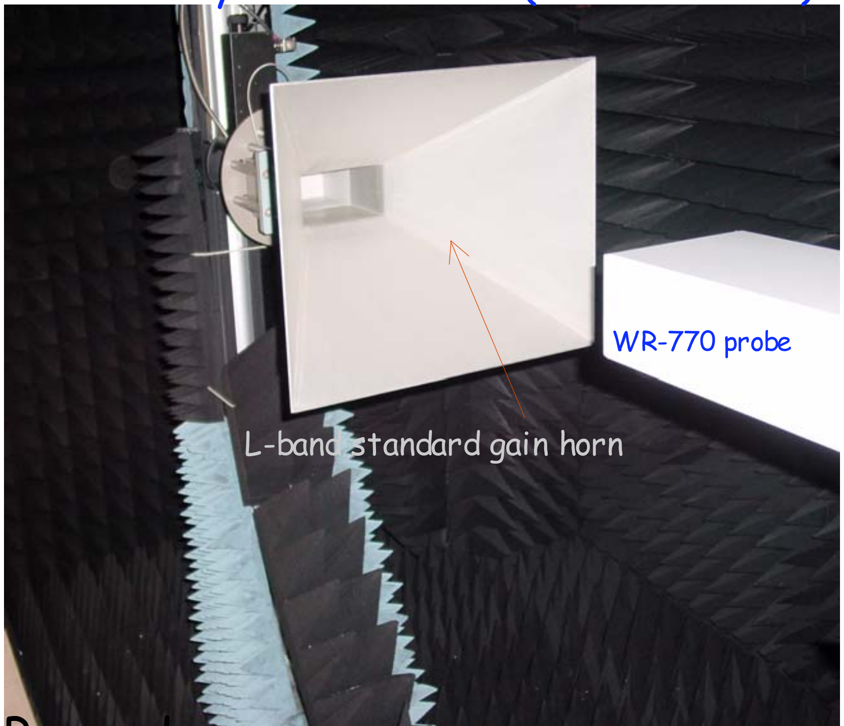
$$Eff = \frac{1/23.99 - 1/322.93}{1/23.99} = 0.926$$

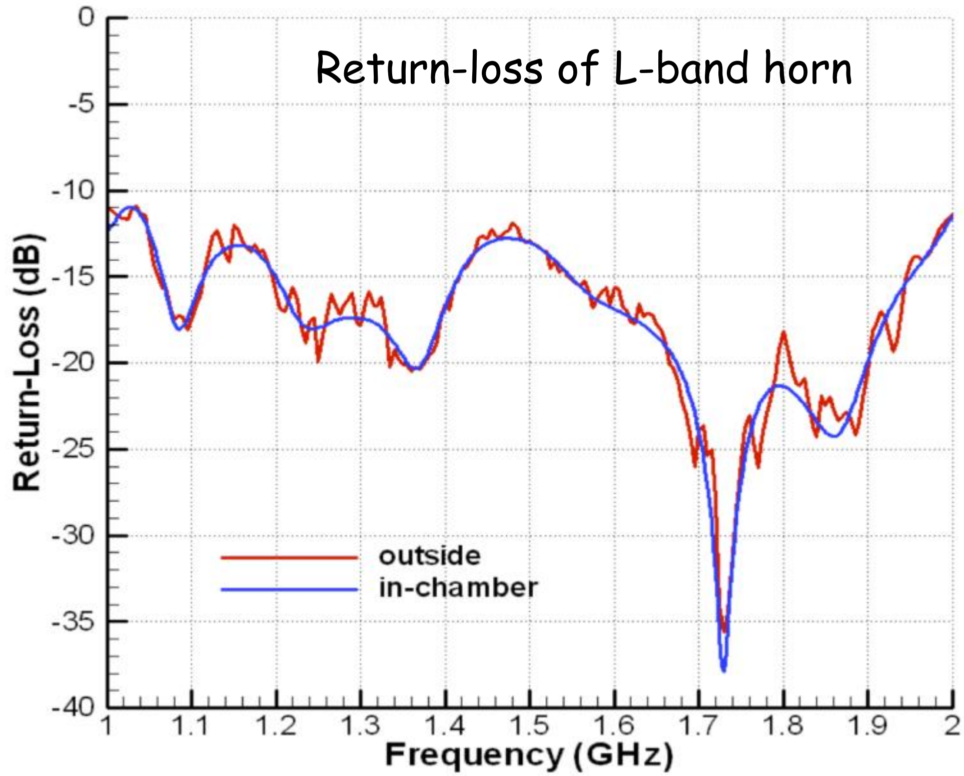


Loss@1.25GHz: 0.33dB (10log 0.926)

# Estimation of Loss of L-band Array from Near-field Measurements

## Directivity/Gain Method (Substitution )



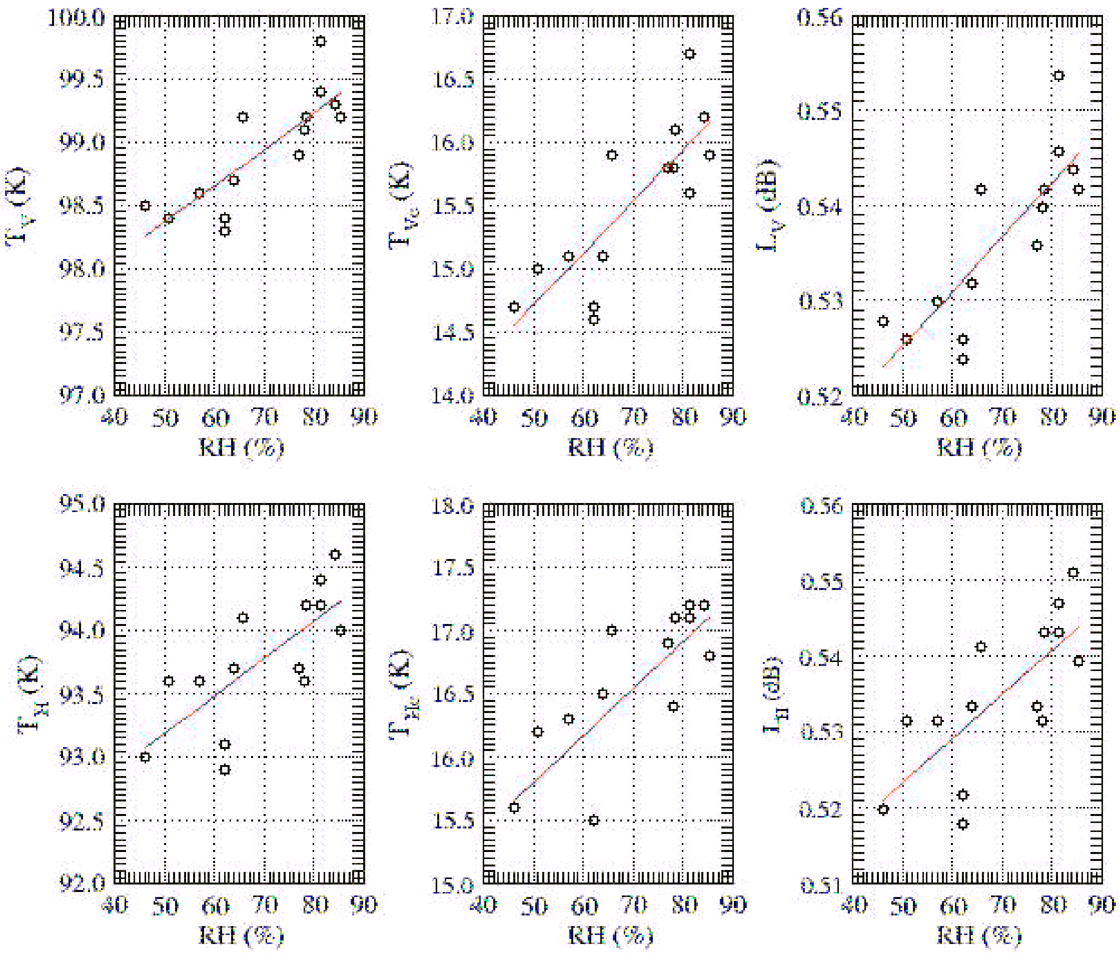

Procedure:

- Comparison of far-field level of L-band array (AUT) to that of a known standard gain horn substituted under the same conditions.
- The difference in signal level is the difference in gain between the AUT and the standard gain horn.

Measured values:

| Parameter | Directivity (dB) | Gain (dB) | Loss (dB) |
|---|---|---|---|
| 1.26GHz | 18.557 | 18.231 | 0.326 |
| 1.413GHz | 19.522 | 19.188 | 0.334 |

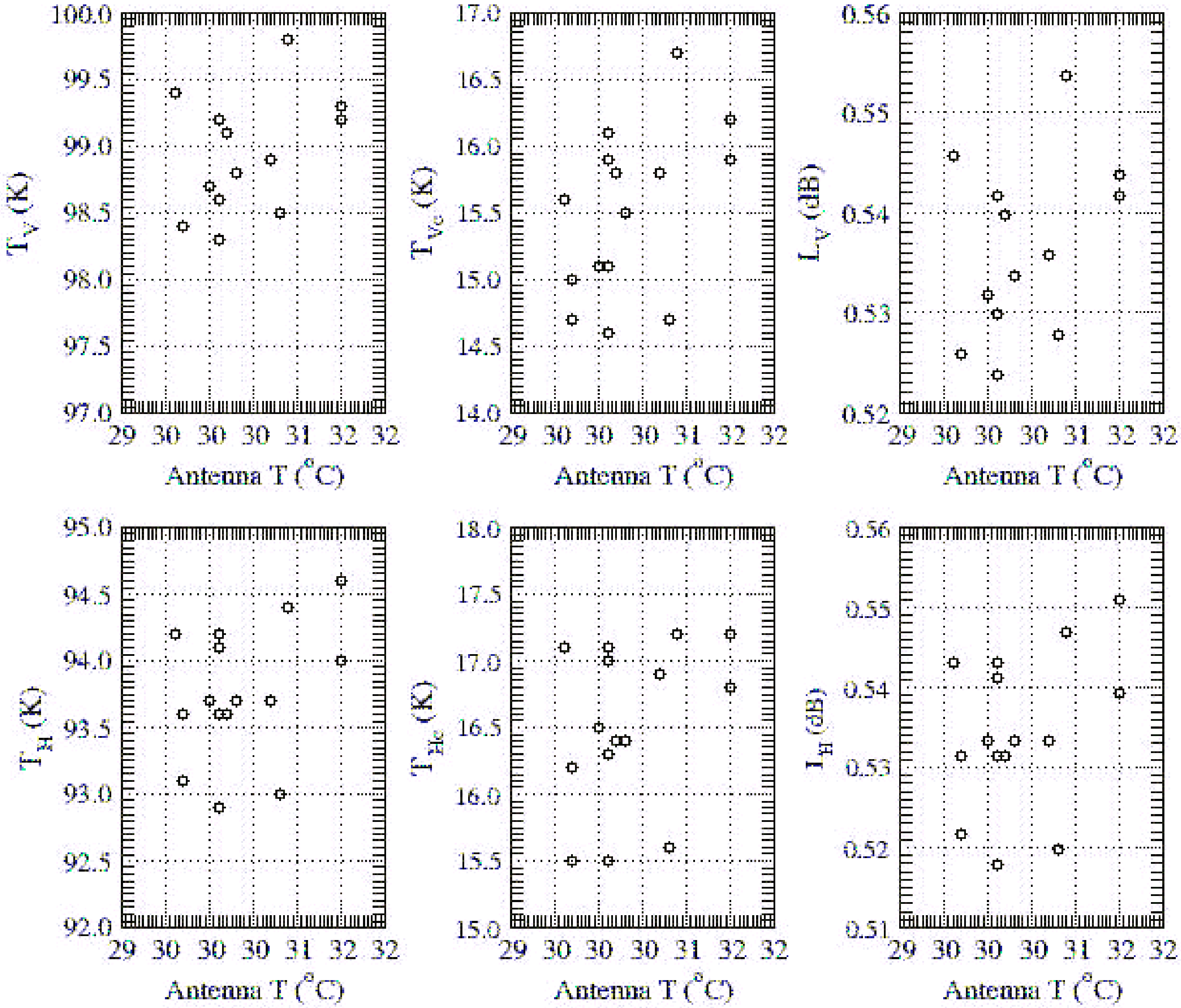
# Strong Correlation with Relative Humidity




| PALS Data | Slope (Regression coefficient) | Correlation coefficient | Standard deviation from the linear regression |
|---|---|---|---|
| Tv | 0.0288 | 0.82 | 0.25 K |
| Tvc | 0.041 | 0.82 | 0.36 K |
| LV | 0.000572 | 0.81 | 0.005 dB |
| Th | 0.0297 | 0.74 | 0.34 K |
| Thc | 0.0371 | 0.76 | 0.40 K |
| LH | 0.000580 | 0.74 | 0.007 dB |

- 0.82 correlation for V-pol and 0.75 correlation for H-pol
- The standard deviation from the linear regression is 0.005 dB for V-pol and 0.007 dB for H-pol

# No Obvious Correlation with Antenna Surface Temperature



# No Obvious Correlation with Air Temperature